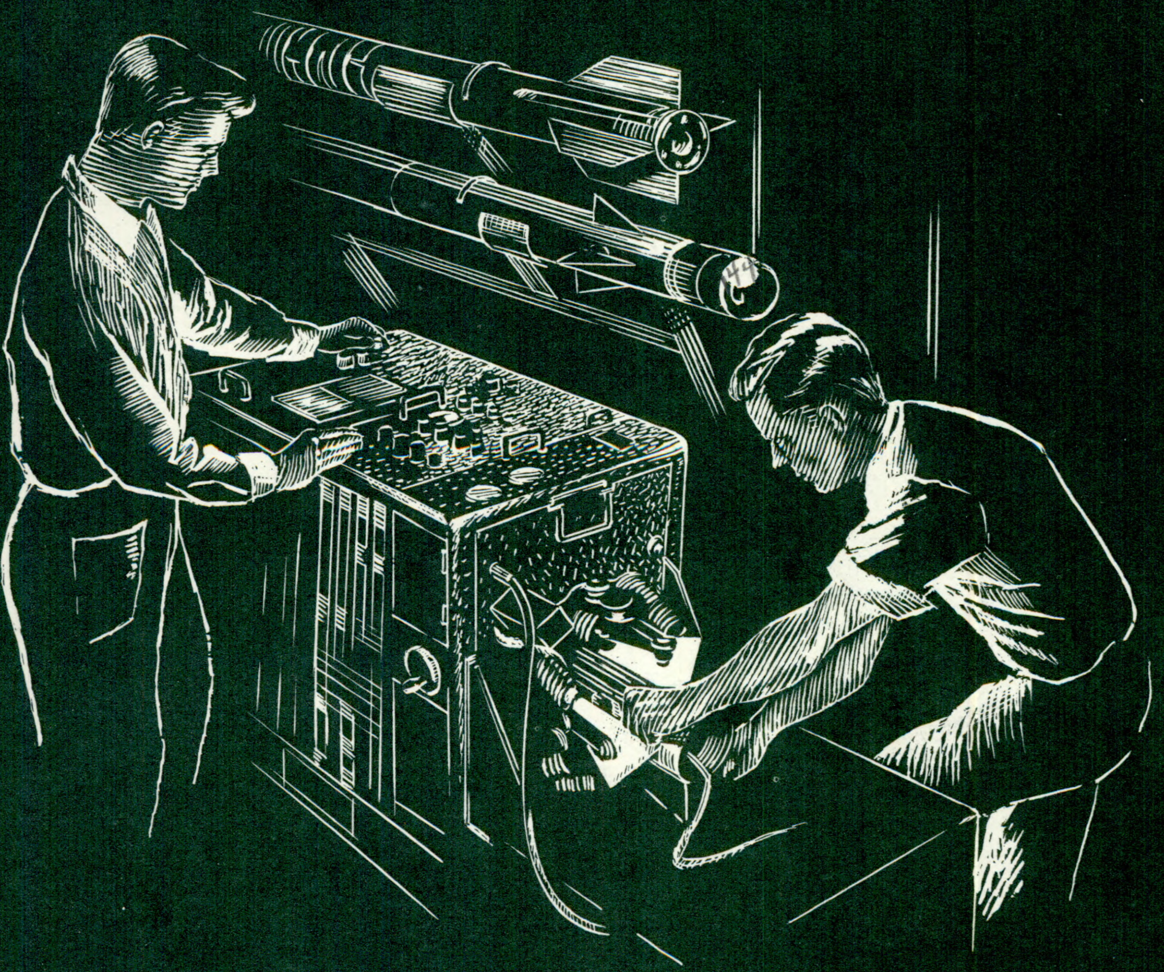


AVIATION GUIDED MISSILEMAN 1 & C

BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSE NAVPERS 10380

AVIATION GUIDED MISSILEMAN
1 & C

Prepared by

BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSE

NAVPERS 10380

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1959

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

PREFACE

This Navy Training Course is the second of a series of courses written to assist enlisted personnel of the Navy and the Naval Reserve who are studying for advancement in the Aviation Guided Missileman (GF) rating. It is based on the qualifications for the rates of GF1 and GFC as given in the *Manual of Qualifications for Advancement in Rating,* NavPers 18068 (Revised). The complete list of professional qualifications applicable to the GF rating can be found in appendix II of this volume.

The chapters of this text are to be studied in conjunction with a considerable amount of supplementary material provided in several basic texts. The principal sources of background material are *Basic Hand Tools Skills,* NavPers 10085; *Basic Electricity,* NavPers 10086; and *Basic Electronics,* NavPers 10087. In addition, the companion text of this course, GF 3 & 2, NavPers 10379, is frequently referenced in the chapters which follow. These courses, together with other Navy Training and USAFI texts containing valuable information for the GF trainee, are included in a reading list just preceding the table of contents.

This book was written by the U. S. Navy Training Publications Center, Memphis, Tennessee. Credit is hereby given to personnel of the Naval Air Weapons Systems School, Jacksonville, Florida and of the Aviation Guided Missileman School, Memphis, Tennessee for reviewing the chapters, for preparing end-of-chapter questions, and for valuable technical assistance.

ACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS*	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7A	E7 to E8	E8 to E9
SERVICE	4 mos. service—or completion of recruit training.	6 mos. as E-2.	6 mos. as E-3.	12 mos. as E-4.	24 mos. as E-5.	36 mos. as E-6.	48 mos. as E-7. 8 of 11 years total service must be enlisted. Must be permanent appointment.	24 mos. as E-8. 10 of 13 years total service must be enlisted.
SCHOOL	Recruit Training.		Class A for PR3, HM3, DT3, PT3.			Class B for AGCA, MUCA.		
PRACTICAL FACTORS	Locally prepared check-offs.	Records of Practical Factors, NavPers 760, must be completed for E-3 and all PO advancements.						
PERFORMANCE TEST			Specified ratings must complete applicable performance tests before taking examinations.					
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.				Special evaluation required.	
EXAMINATIONS	Locally prepared tests.		Service-wide examinations required for all PO advancements.				Service-wide and selection board.	
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Required for E-3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed.						
AUTHORIZATION	Commanding Officer		U.S. Naval Examining Center			Bureau of Naval Personnel		
	TARS are advanced to fill vacancies and must be approved by CNARESTRA.							

*All advancements require commanding officer's recommendation.

INACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS*		E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7A
	FOR THESE DRILLS PER YEAR						
TOTAL TIME IN GRADE	24 OR 48	9 mos.	9 mos.	15 mos.	18 mos.	24 mos.	36 mos.
	12	9 mos.	15 mos.	21 mos.	24 mos.	36 mos.	42 mos.
	NON-DRILLING	12 mos.	24 mos.	24 mos.	36 mos.	48 mos.	48 mos.
DRILLS ATTENDED IN GRADE#	48	27	27	45	54	72	108
	24	16	16	27	32	42	65
	12	8	13	19	21	32	38
TOTAL TRAINING DUTY IN GRADE#	24 OR 48	14 days	14 days	14 days	14 days	28 days	42 days
	12	14 days	14 days	14 days	28 days	42 days	42 days
	NON-DRILLING	None	None	14 days	14 days	28 days	28 days
PERFORMANCE TESTS				Specific ratings must complete applicable performance tests before taking examination.			
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)		Record of Practical Factors, NavPers 1316, must be completed for all advancements.					
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Completion of applicable course or courses must be entered in service record.					
EXAMINATION		Standard exams are used where available, otherwise locally prepared exams are used.					
AUTHORIZATION		District commandant or CNARESTRA					BuPers

*Recommendation by commanding officer required for all advancements.
#Active duty periods may be substituted for drills and training duty.

READING LIST

NAVY TRAINING COURSES

Aviation Guided Missileman 3 & 2, NavPers 10379
Aviation Electronics Technician 1 & C, NavPers 10318
Basic Hand Tools Skills, NavPers 10085
Basic Electricity, NavPers 10086
Basic Electronics, NavPers 10087
Basic Hydraulics, NavPers 16193
Blueprint Reading and Sketching, NavPers 10077-A

USAFI TEXTS

United States Armed Forces Institute (USAFI) courses for additional reading and study are available through your Information and Education Officer.* A partial list of these courses applicable to the GF rating follows:

CORRESPONDENCE

Number	Title
290	Physics I
291	Physics II
781	Fundamentals of Electricity
887	Intermediate Radio
890	Radio Servicing and Repair I
891	Radio Servicing and Repair II
892	Frequency Modulation

*"Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more, or if they have been on active duty for a period of 120 days or more, regardless of the time specified in the active duty orders."

CONTENTS

AVIATION GUIDED MISSILEMAN
1 & C

CHAPTER 1

DUTIES AND RESPONSIBILITIES

Objectives and Content of the Course

Education in the Navy is a continuing process, beginning the day a recruit starts his training and ending for career personnel only on retirement. This course, a part of the Navy's technical training program, is one of the many training courses prepared to assist personnel studying for advancement in rating. It is one factor in a training procedure that involves as major elements the trainee and the GF rating. Its primary objective is to aid in bringing these into an effective working unity. The vital element in this procedure is you, the trainee. The second element consists of the specific objectives that must be met, the qualifications that must be met, and the responsibilities that must be accepted, learned, and mastered. These are some of the demands which must be satisfied in order for you to advance to a higher rate.

ADVANCEMENT IN THE GF RATING

At the time of writing this course, the Navy is engaged in a revolutionary program of developing and perfecting new weapons. Among the leaders in the program is the guided missile. Supplementing the missile, as one of the key factors in this phase of naval history, are the men who fill the missileman billets.

Advancement to the higher rates of GF1 and GFC entails challenge—the challenge of greater responsibility and additional duties, of working with people, and of the need for broader technical knowledge. The rewards of advancement are ample. They include, of course, the incentive of higher pay and the opening of the path leading to commissioned officer status. Less tangible, but fully as rewarding, are the enhanced authority, responsibility to assume leadership, and the satisfactions which result only from achieving competence in a field that demands higher-than-average intelligence and ability.

The scope of requirements for advancement is wide and includes both general and specific demands. The general demands of the rating can be summarized in the following statement:

"Aviation Guided Missilemen assemble, test, aline, adjust, replace, and repair internal components of air-launched missiles, excluding propulsion systems and ordnance items and hydraulic/pneumatic systems not associated with missile internal guidance and control; operate, test, adjust, aline, calibrate, and repair missile test equipment; supervise and train personnel in testing and repair of guided missile sections and components and associated test equipment; maintain logs and equipment histories."

The specific requirements for advancement in rating consist of both military and professional qualifications. The professional "quals" constitute the basis upon which this text is constructed. They consist of those listed in the *Manual of Qualifications for Advancement in Rating,* NavPers 18068 (Revised) for GF1 and GFC. The entire list of professional qualifications can be found in appendix II.

The contents of this course include material contained in this volume and also information found in companion texts. These consist principally of titles in the following list, which is by no means exclusive:

Basic Electricity, NavPers 10086.
Basic Electronics, NavPers 10087.
Basic Hydraulics, NavPers 16193.
Aviation Guided Missileman 3 and 2, NavPers 10379.

In addition to the listed qualifications, this volume contains chapters on magnetic amplifiers and transistors as employed in the circuitry of missiles and missile test equipment. A major portion of this text is devoted to missile testing in both systems and component forms, while the concluding chapter is concerned with the fundamental clerical forms and procedures employed by missilemen.

RELATED PUBLICATIONS

The specific requirements for advancement to GF1 and GFC are stated in several publications, among which are (1) the *Manual of Qualifications for Advancement in Rating,* and (2) *Record of Practical Factors,* NavPers Form 760. Pertinent bibliography is listed in the annually published *Training Publications for Advancement in Rating,* NavPers 10052.

Manual of Qualifications for Advancement in Rating, NavPers 18068 (Revised)

This publication is the official source which gives the minimum qualifications for advancement in rating. It applies to all enlisted personnel of the Navy and Naval Reserve. It serves as a guide for those concerned with training and advancement of enlisted men, and is used in accordance with directives issued by the Bureau of Naval Personnel.

An important feature of the "Quals" Manual is the procedure by which it is revised. Changes in the manual which incorporate revised qualifications for certain ratings are issued at various times. These revisions are based on recommendations of the fleet and technical bureaus, the results of research studies, and on approved recommendations of the Board of Review of the Enlisted Rating Structure. It is necessary that the trainee consult the latest change in the Quals Manual and note carefully any modifications affecting the quals of his particular rate. (The qualifications listed in appendix II are valid through Change 13.)

With Change 11, there appeared some revisions in the structure of the quals manual. Among these is included a revised format in which the qualifications in some ratings are grouped under subject-matter areas rather than under the broader functional headings (such as Operational, Maintenance and/or Repair, and Administrative and/or Clerical). In subsequent changes, this format will be used in listing the quals of all the various ratings.

Record of Practical Factors, NavPers Form 760

The standard form, NavPers 760, *Record of Practical Factors,* has been prescribed for all active duty personnel by the Bureau of Naval Personnel. A special form is available for each rating. The principal content is a listing of the military and professional practical-factor requirements which are mandatory for advancement in rating. In addition to the pertinent factors, the form provides space for the supervising officer to date and initial the completion of each factor. A space is also provided for making changes in the factors, and directions are given for forwarding the information contained from one duty station to another.

The record is usually kept by the division officer. When the trainee is transferred, his *Record of Practical Factors* is signed, inserted in the correspondence side of his Enlisted Service Record, and forwarded to his new duty station. In this manner, the record is kept up to date and is employed on a continuing basis as the man progresses in his rating.

Bibliography of Training Courses

A source of essential information for those preparing for advancement in the GF rating (as well as in other ratings) is provided by the *Training Publications for Advancement in Rating,* NavPers 10052. This booklet, issued annually by the Bureau of Naval Personnel, lists Navy Training Courses and other publications required or recommended for study in preparing for advancement. The required courses are indicated by asterisks. Those so marked must be completed by the trainee at a given rate level before he is eligible for recommendation to take the rating examination for the next higher rate. In addition, basic courses, general courses, and study guides are listed in the bibliography which provide valuable sources of supplementary information.

When using the bibliography, it must be realized that personnel of all higher pay grades listed in the booklet are held responsible for the materials in the publications listed for the lower rates of that particular rating. Since, in many instances, only pertinent sections of publications are specified in the *Training Publications for Advancement in Rating,* the most intelligent use of this booklet will be made by concurrent reference to the Qualifications Manual.

HOW TO STUDY THIS COURSE

In this section a method of study is described that is recommended for use with this course as well as with other courses and training publications listed in NavPers 10052. The procedure is based on the principal techniques that

have been found most effective by trainees studying Navy Training Courses. It is outlined in the following paragraphs, which are quoted from the *Naval Training Bulletin:*

"Start by reading the preface, table of contents, and index. Then thumb through the entire book, looking at the illustrations and reading bits here and there as your eyes fall on something interesting. This browsing will show you how the book is organized and the subject matter it covers.

"Next, preread the entire course. Do this to learn the relationship of parts and chapters to the whole of the rating covered in the course. Read the introduction to each chapter. Then read the headings and subheadings and finally the summary, if the chapter contains one. Ask yourself such questions as: What am I expected to know about this process or technique?

"Learn the qualifications for advancement in the rating (in the appendix). You are studying the NTC in order to meet these 'Quals.'

"These preliminary steps orient you and help you plan your study. They put you in a better position to draw on personal experience and to relate your past experience to the new material.

"After this preliminary work, you are ready to fill in the details by intensive study of the chapters, sections, and subsections. What you can cover during a study session depends on (1) the difficulty of the material; (2) what you already know about the topic; and (3) your skill as a reader. At any rate, for each study session, plan to master a predetermined unit of material: an entire chapter or a major section of a chapter.

"Use the prereading system with each section and paragraph. Skim the introduction, headings, first and last sentences of each paragraph, and all summarizing statements. As you preread, think up questions about the material. Write down these questions for future reference. Another useful technique is to make an outline during prereading, filling in the details later. When you have finished prereading, think about what you have learned thus far. Ask yourself such questions as: What main ideas are presented? What details must I look for?

"Next, read the entire chapter or section completely and carefully. As you read, be on the lookout for the questions you have thought about or the details of your outline. Relate the part to the whole. Relate your previous knowledge and background experience to the discussion. Identify yourself with the situations, process, and techniques; visualize yourself doing the things that are described.

"Recite what you have learned. This is the proof of understanding. Look at the questions you wrote down during prereading. Do you know the answers? Can you answer the questions in the quiz at the end of the chapter? Try to master the material you are studying before proceeding to a new portion of the text."

The GF1 and GFC

Advancement to GF1 or GFC means new duties and responsibilities. In general, these added functions are those which can be grouped under the heading of leadership. They include supervision, training, and administrative activities, in which the petty officer works with people in his primary work area.

The higher-rated GF petty officer is at once a military leader and a technical specialist. These two branches of his qualifications cannot be sharply divided since the two functions combine as one in practice. However, for purposes of discussion, these can be differentiated in accordance with the source materials and publications from which the trainee gains information in order to meet the specified requirements.

The military qualifications involved in advancement to GF1 and GFC are amply treated in the publication *Military Requirements for Petty Officer 1 and C,* NavPers 10057. The professional qualifications are listed in this text in appendix II. An overall evaluation of the latter reveals that the petty officers of the higher grades must attain proficiency in the basic areas of supervision, training, and administrative skills, and that in this regard, their requirements differ principally from those of the lower pay grades.

When the GF 1 or C is concerned with the administration and training of his crew, it is necessary that he have a good understanding of personnel management and of the rules and regulations regarding his crew as well as those stipulating his own authority in personnel matters. Personnel management is largely the process of accomplishing results through the efforts of other. The effectiveness with which the results are attained is a reflection of the success of an administrator.

Too strong an emphasis cannot be placed on leadership and administration in the higher levels of the GF rating. The following brief description is a review of the factors essential to good personnel administration.

Personnel administration is defined as the science of getting things done through planning, supervision, direction, and coordination. It involves:

1. Motivation—the stimulation of individuals to put forth their best efforts to accomplish their assigned tasks.
2. Discipline—the exercise of control over the conduct of individuals.
3. Leadership—the technique of instilling loyalty and common purpose in individuals.
4. Organization—the assignment of individuals to certain tasks, duties, and associated responsibilities.
5. Training—the instruction of individuals in their duties in order that their efforts may result in more productive performance.

The directions the senior GF must follow and the criteria he must use as a guide are contained in many publications. Among the most important are the *Bluejackets' Manual*, the *Petty Officer's Guide*, and books that have been developed for officers, but which are useful to petty officers also (the *Naval Officer's Guide* and the *Division Officer's Guide*). For the most detailed information and explicit examples of guide lines for PO 1 and C, reference should be made to the above mentioned *Military Requirements for Petty Officer 1 and C*. This excellent manual covers many phases of the military qualifications of the senior grades.

In a supervisory capacity, the GF1 assigns and supervises personnel in such tasks as charging pressurized systems, replacement of electronic parts and components, and in performing missile system and component tests. He must be qualified to conduct on-the-job training in the subject areas of basic electricity, electronic circuit principles, and the elements of hydraulic and pneumatic mechanisms. He is required to know and to employ authorized procedures in testing and missile handling in addition to such clerical and administrative duties as taking inventories of missile and test equipment, the use of allowance lists, and requisitioning and procurement processes.

The GFC must be capable of serving as a safety expert, skilled in detecting unsafe work conditions and practices, and in instructing his personnel in authorized safety precepts. He must know the art and science of organization, being charged with the responsibility of making work assignments in missile shops, in maintenance work in squadrons, ships, and shore-based activities. He must be able to conduct inventories of equipment, spare parts, and associated materials and is required to qualify as an instructor of lower-rated men in such typical subject areas as

1. Missile theory as it pertains to specific missiles, circuits, and components thereof, and the operation and maintenance of related test equipment;
2. Procedures in making directed modifications in electronic and electrical equipment;
3. Principles and practical operation of servomechanisms; and
4. Functions and principles of hydraulic and pneumatic systems and components.

THE GF AS A TECHNICAL SPECIALIST

As a technical specialist, the GF petty officer has several major areas of duties and responsibilities. In addition to supervision, he functions as part of the supply or logistic organization which insures an adequate supply of material to expending activities. He is also responsible for various training projects which require skill and experience in applying standard training procedures and, in addition, must be able to apply his knowledge in the utilization of special missile training devices. In the performance of these duties involving maintenance and logistics, the GF fills a key position in the missile organization.

The Missile Maintenance and Logistic Organization

It is desirable to indicate the background organization in which the functions of testing, maintenance, and supply are accomplished. This is shown in simple form by the flow-chart diagram in figure 1-1, a composite of the major elements of the air-launched missile organization. In addition to the manufacturer, the elements include Naval Ammunition Depots, Overhaul and Repair activities, aircraft carriers, and aircraft squadrons.

Personnel billeted at Naval Ammunition Depots (NAD) receive, store, and issue complete guided missiles. They perform systems tests and component checks; and are required to inspect and make replacements of missile sections. They replace damaged structural parts of missiles and repair and maintain assigned missile systems and component test sets. The functions of area stock and issue control are carried out at NAD in response to orders or drafts from authorized commanders.

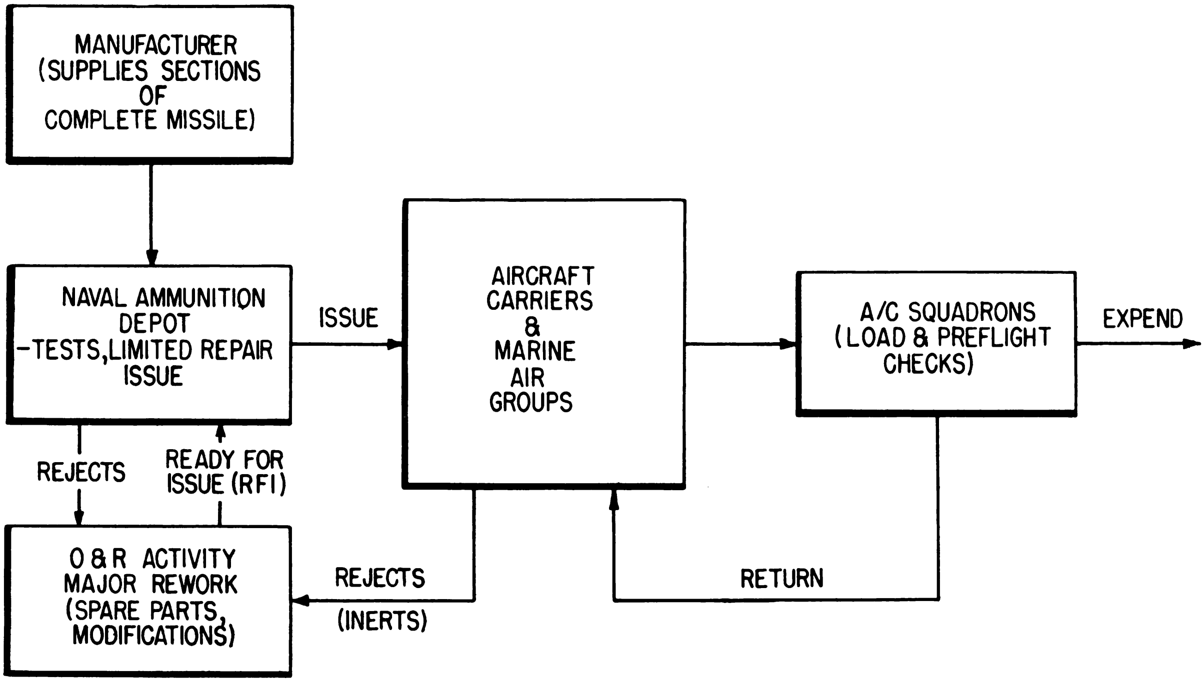


Figure 1-1.—Air-launched missile maintenance and logistic organization.

Overhaul and Repair activities are parts of Naval Air Stations; and as major shore-based organizations, they play a significant part in the missile logistic system. Missilemen assigned to these activities perform necessary rework on "inert" or rejected guidance and control sections to make them ready for issue (RFI). Other typical duties include performing modifications on missiles and missile test equipment when such modifications are beyond the capabilities of other fleet or shore activities.

Missilemen assigned to aircraft carriers or other support activities are required to be proficient in the following typical duties: performance of automatic checkout procedures (GO, NO-GO checks); assembly and loading, and replacement of removable sections and components.

Missilemen duties in connection with aircraft squadrons include preflight checking, and missile servicing, the latter term indicating the preparation of missiles for launching.

Special Skills and Knowledge Required

Numerous special skills and knowledge are required of personnel at the GF1 and GFC levels. Some of the fundamental areas include assembly procedures; the proper use of support equipments; and techniques with missile fluid and electronic components.

Some indications of the missileman's required know-how can be conveyed by showing representative examples of special handling equipment (fig. 1-2) and special tools (fig. 1-3).

Typical of the duties of the GF1 and GFC are supervision and training of personnel in functions such as those illustrated in figures 1-4 and 1-5. The former shows the devices and procedures used in charging an air bottle, the primary energy source for the pneumatic control system of a typical air-launched missile. Figure 1-5 shows the method of making a crystal installation in the guidance section of a radio command weapon.

Handling and Servicing

Among the essential skills and special knowledge of GF personnel of the higher pay grades are those required in working with and supervising missilemen aboard ships having missile capabilities. The major tasks carried out in this locale include stowage and testing; organizing and supervising the breakout supply chain; assembly; and delivery and loading aboard aircraft. The general nature of the organization into which men of the GF rating are integrated aboard ship can be indicated by means of the flow chart shown in figure 1-6. The basic functions of the systems illustrated

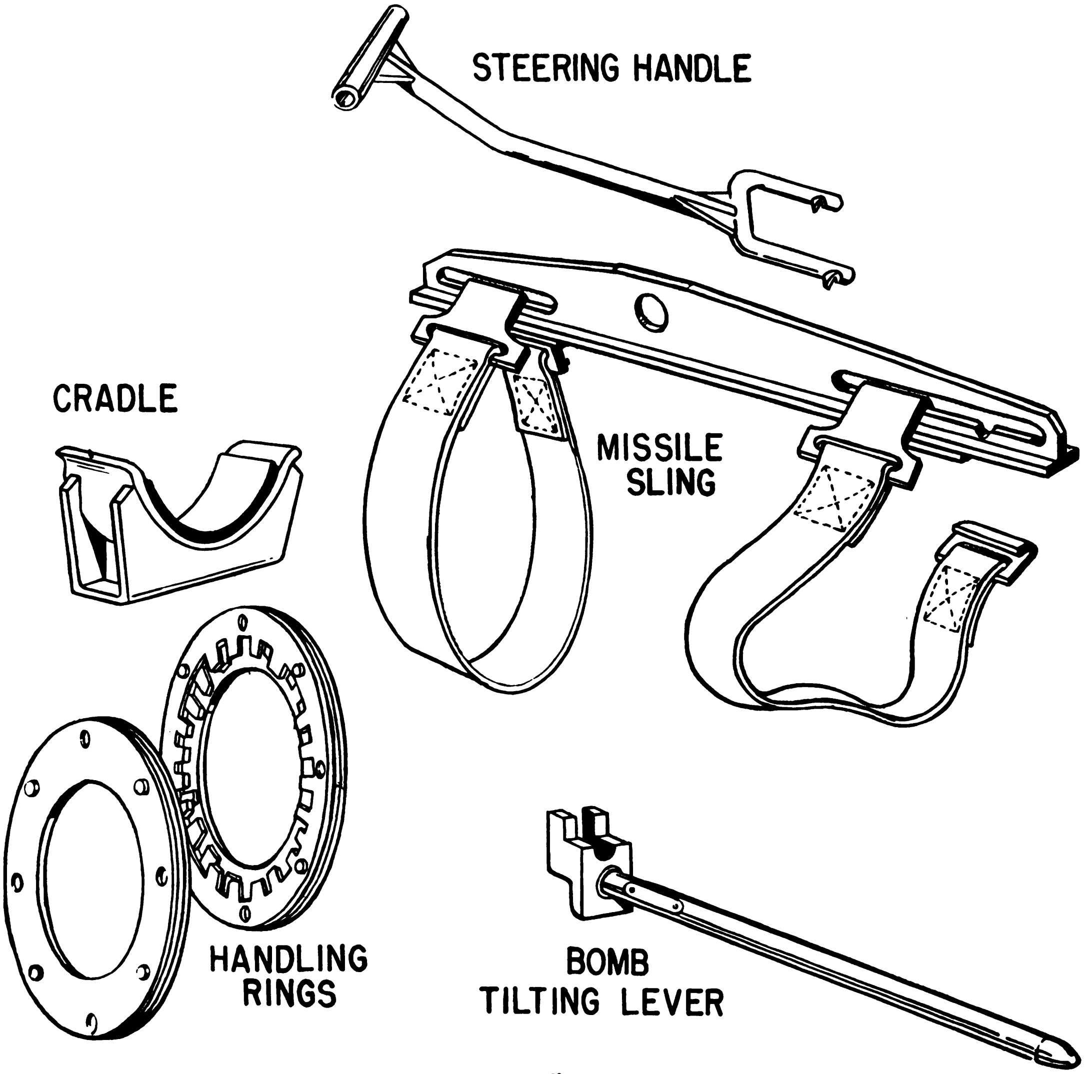


Figure 1-2.—Handling equipment.

are those required in (1) receiving, decanning, and stowage, and (2) operation of the breakout chain which involves assembly, delivery, and loading.

Missilemen active in the shipboard supply system (fig. 1-6) perform typical duties of the type briefly summarized in the following paragraphs. Missile sections, auxiliary tools, and associated equipment are loaded aboard the carrier in accordance with standard Navy procedures and then taken below decks for stowage. The various missile sections are either unpacked upon receipt or stored below in their containers, depending on the nature of the sections. With some missiles, no test or checkout procedures are required; with others, authorized handling instructions require that guidance and control sections be given an operational checkout.

Motors and wings are placed aboard appropriate transportation vehicles for transfer to predesignated stowage compartments. Explosive items such as warheads and fuzes are stowed in appropriate compartments in accordance with existing regulations. With missiles requiring checkout of G and C sections, typical procedures direct that these sections be subjected to operational checks periodically (about once every four months) while in stowage; while missiles in ready service areas require replacement of the G and C section more frequently (about once a month in most cases).

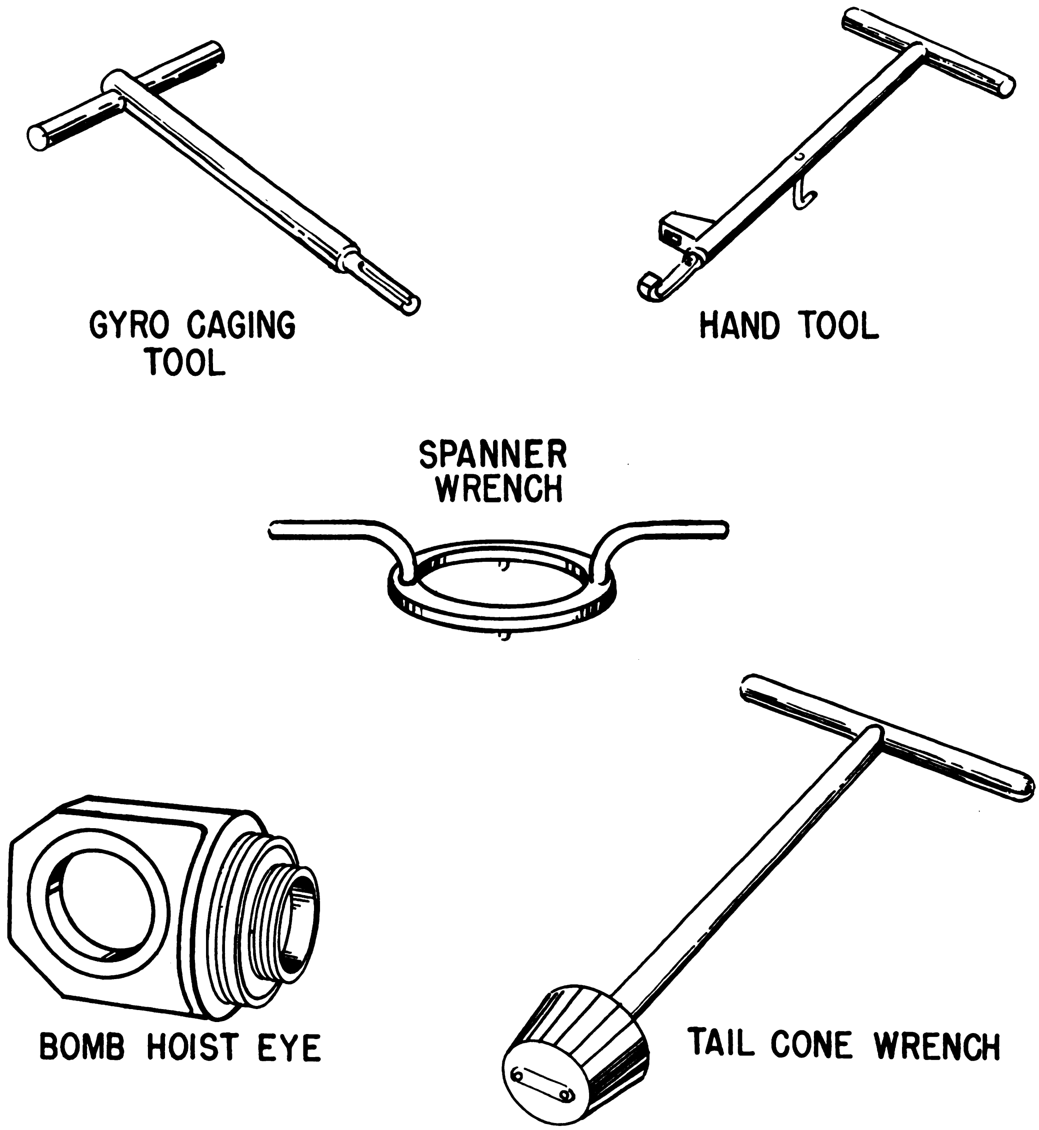


Figure 1-3.—Special tools.

SUPPLY AND ASSEMBLY TEAMS

Typical of the duties of missilemen assigned to assembly and supply teams are those involving the movement of missile sections to assembly areas where the mating of the sections takes place. Some sections are hand carried, others are transported on skids or other authorized handling equipment. At the assembly area, the basic missile sections are placed in assembly jigs; the wings and fins are attached; fuzes are installed; and warhead and motor sections are joined to the major assembly. In some cases, protective covers are provided for the nose of the missile. These usually remain in place until the missile is aboard the aircraft and ready to be launched. Assembly operations require the use of special tools such as pneumatic screwdrivers, jigs with provisions for proper alinement and indexing, and other special purpose equipment.

The completely assembled missiles from either the assembly area or the ready-service magazine (fig. 1-6) are loaded aboard the bomb elevator (transferred at hangar deck level to aircraft elevators on some ships), and upon arrival at the flight deck are moved to the assigned aircraft. Before attaching missiles to

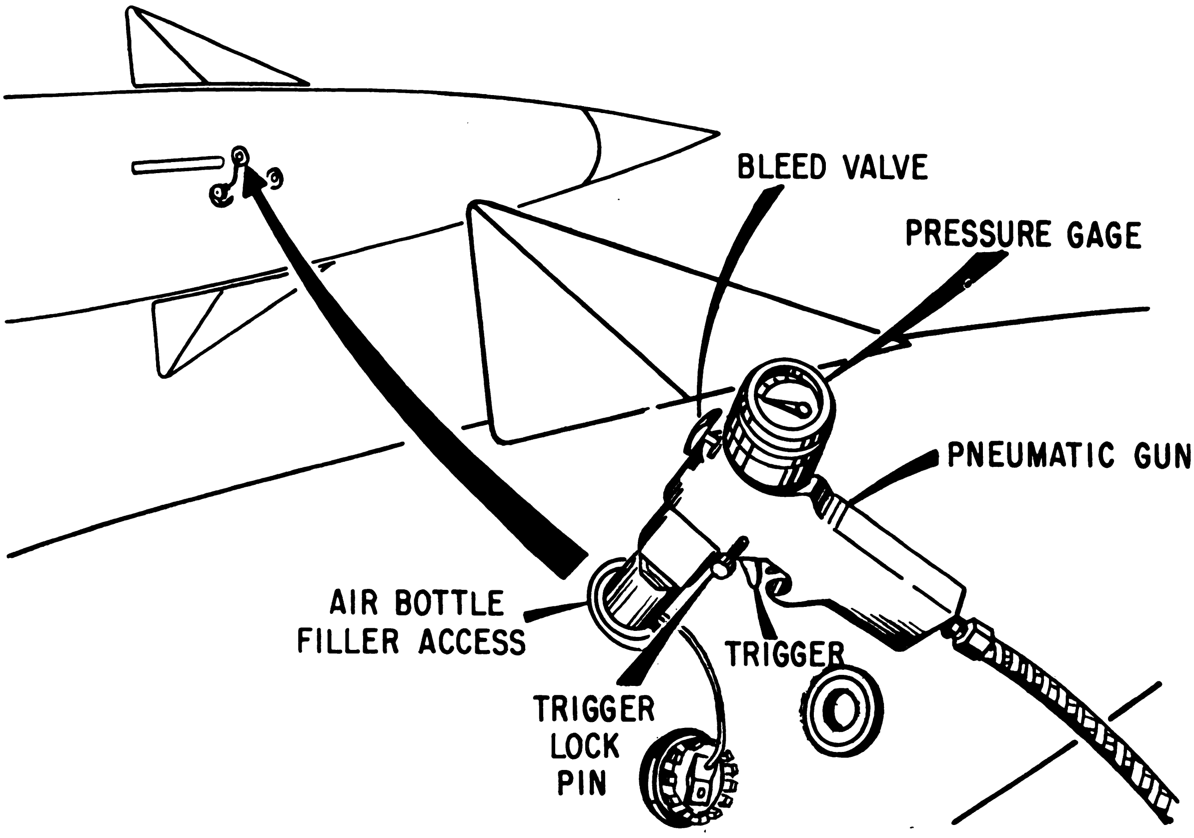


Figure 1-4.—Charging air bottle.

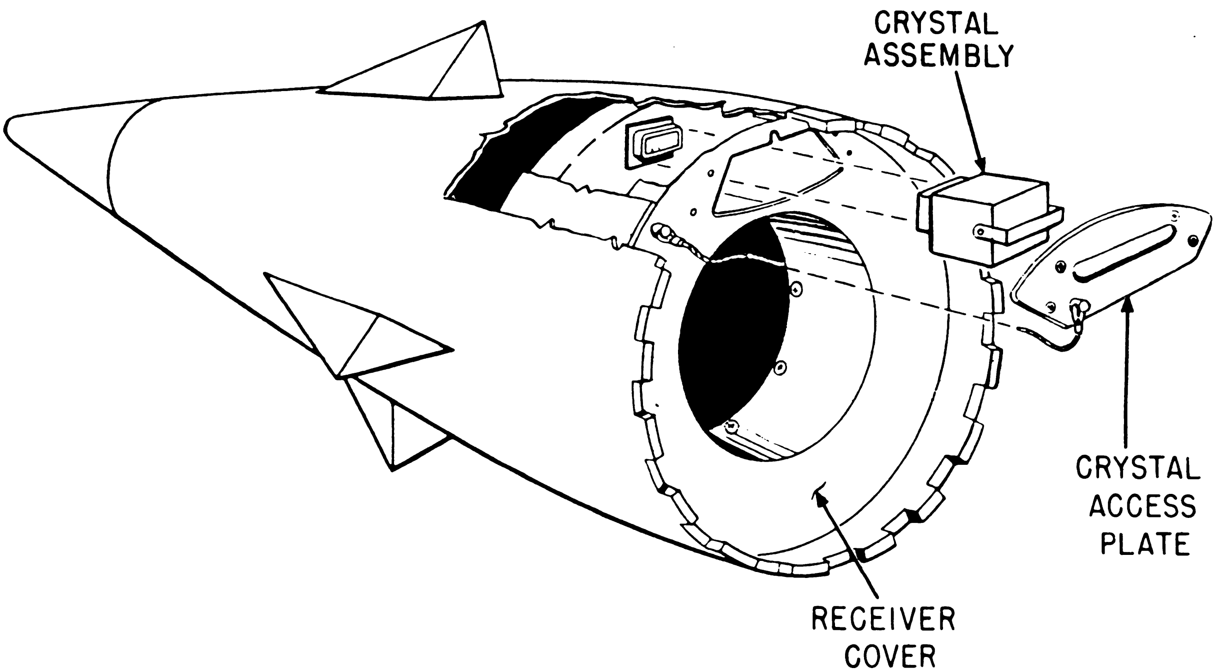


Figure 1-5.—Crystal installation.

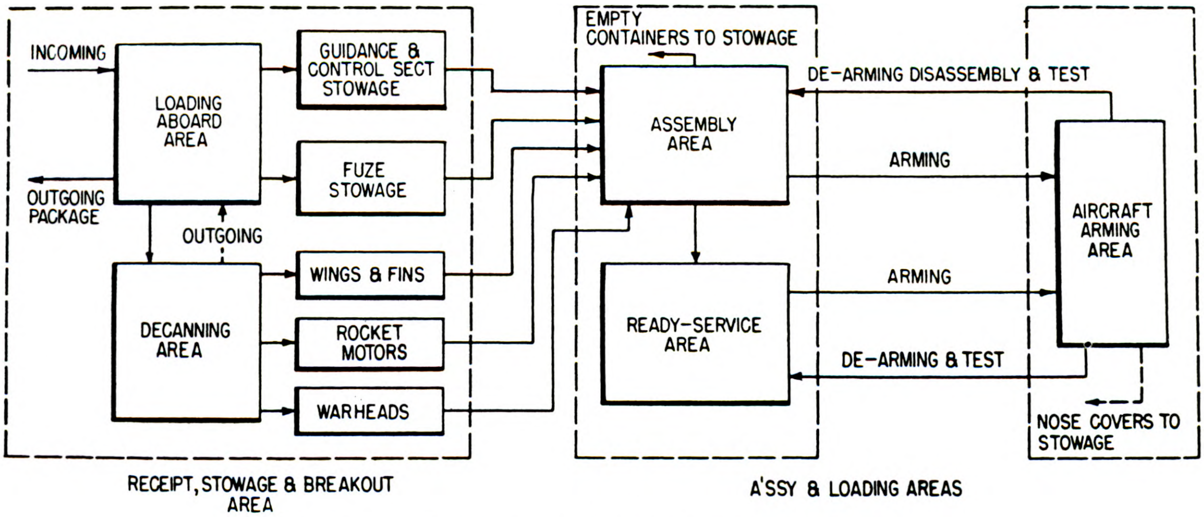


Figure 1-6.—Flow chart of missile components aboard ship.

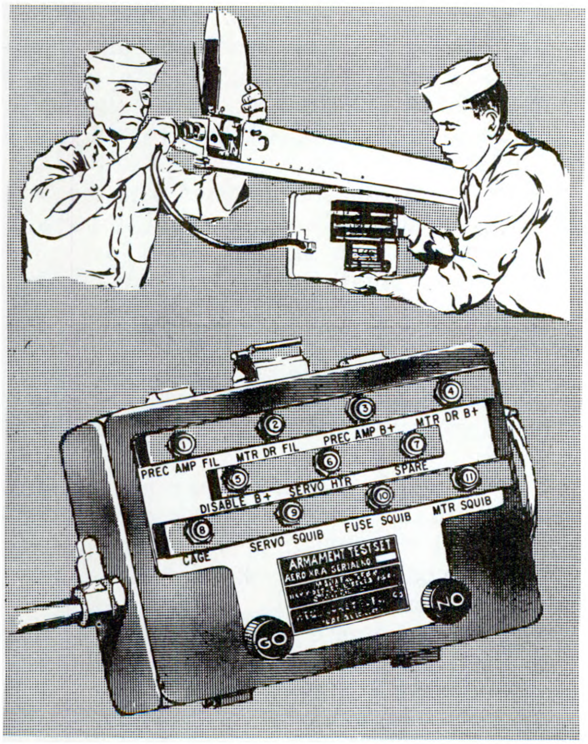


Figure 1-7.—Launcher tester.

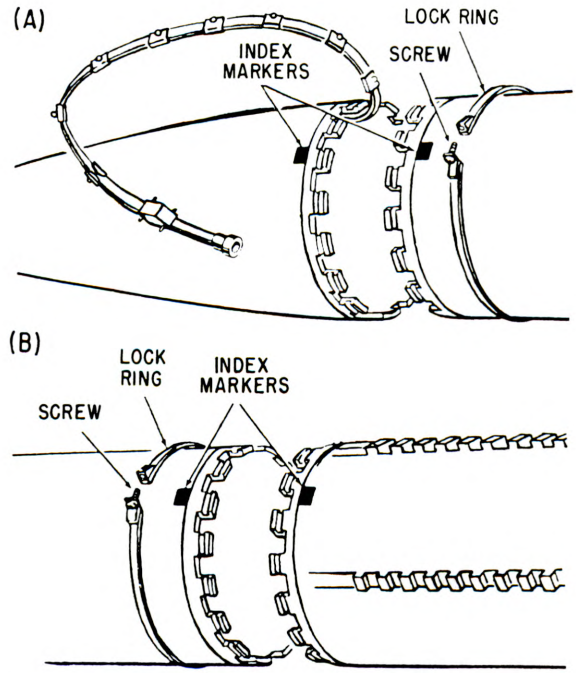


Figure 1-8.—Splicing fore, aft, and center sections.

aircraft launchers, the latter are checked out (usually by means of a special purpose tester of the type shown in figure 1-7) and, following satisfactory checkout, the missiles are loaded on the launchers.

Additional duties of GF personnel include manning assigned elevators, charging pneumatic accumulators, and installation of batteries in those missiles which employ them. Normally, charging processes are accomplished in the ready-service magazine and batteries are installed when the plane is on the catapult. Representative procedures employed in assembly include those shown in figure 1-8 which illustrates the splicing of major sections of a missile.

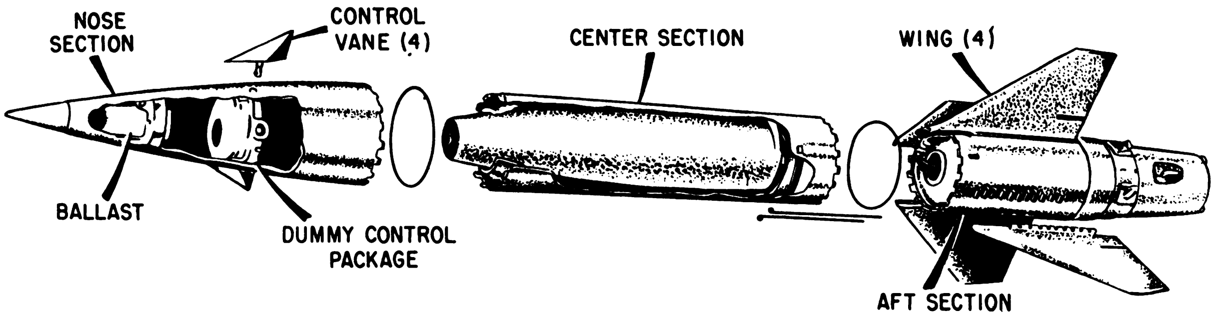


Figure 1-9.—Training missile.

SPECIAL TRAINING PROCEDURES

Training is one of the essential responsibilities of petty officers at the first class and chief levels. The GF petty officer employs general procedures of training that are used in all types of technical instruction; but he is also required to know and apply special methods and special training equipment which are characteristic of his own rating.

The major elements of Navy technical instruction are given in chapters 3 and 4 of *Military Requirements for Petty Officer 1 and C*, NavPers 10057. The chapters referenced treat the subjects of training responsibilities, the use of training aids, and the area of testing and test methods. Special procedures in missile training often involve the use of highly developed devices, an example of which is given in figure 1-9, a drawing of a typical training missile.

The training missile is used to familiarize missilemen with authorized procedures for assembling and handling the operational weapon. The physical characteristics, dimensions, and weight of the training missile are similar to those of the operational vehicle; however, there are certain necessary differences which are typical of devices of this class. For example, the training missile center section contains an inert warhead and a dummy fuze instead of the live ordnance items used in the actual weapon. The control section in the nose of the trainer is a dummy unit, and ballast is added to maintain the correct weight and balance. The support equipment (special tools and handling gear), uncrating processes, and assembly procedures for the training unit are the same as those for the actual weapon except for the pneumatic and electronic components which are not present in the trainer.

When the GF1 or GFC is assigned as a training petty officer, his duties encompass two areas: (1) operational and maintenance training, and (2) advancement in rating training. As the training petty officer, he has many general responsibilities as indicated in the following list. He should

1. Carry out the details of the training program of the missile division and make weekly reports as required to appropriate officers;
2. Maintain necessary files, charts, or cards to show the progress of all personnel in the division;
3. Work out, in coordination with the Division Officer and the Leading Chief, a schedule which insures that all personnel are made available on a rotational basis to participate in the training program both as students and as instructors;
4. Utilize all the talent in the division by assigning leading petty officers subjects on which to prepare lectures or to give on-the-job training;
5. Review the training program from time to time with the Division Officer and revise it to cope with the situation, material available, or with the special requirement of the activity's current operation;
6. Keep available and corrected to date necessary technical publications and printed matter for training; and
7. Act as an evaluator in the qualification of division personnel in practical factors for training in rate.

PROCUREMENT AND SUPPLY

Among the essential duties of the GF1 or GFC are those which involve knowledge of supply and procurement procedures. Many fleet personnel are familiar with the Bulk Spares and Operating Spares systems in use during

World War II. Some of the disadvantages of these systems were uneconomical use of shipping space resulting from bulky packaging of small parts; excessive procurement of many items, particularly those used in many equipments; and the frequent failure of personnel to make immediate reorders of replacements for parts taken from the spares box.

The present system of supply is based on stocking spare parts by type rather than by consideration as to where they are used. This system is presently employed in the procurement and distribution of electronic items; and among its results are substantial monetary savings and increased efficiency as compared with the older methods. Today, for example, typical procurement of a major electronic equipment might include about 40 percent complete spare equipment and about 42 percent of the total money value of the equipment might be obligated for spare parts.

In order to assist the trainee in gaining a working knowledge of the supply system, the following brief summary concerning funds, appropriations, and procurement procedures is given.

Funds

Funds are generally defined as sums of money or other resources which may be expended for authorized purposes. There are several classes of funds of importance in naval supply, the principal one being that represented by the General Fund.

The General Fund is composed of receipts of the United States obtained from general sources. A withdrawal from it can be made only in accordance with an appropriation made by Congress for the purpose of carrying out general and ordinary operations of the Government. For example, the Navy Stock Fund is established by appropriation of money in the General Fund.

The Navy Stock Fund, a revolving fund within the General Fund, is used for procurement of general stores and supplies (other than technical items) needed for maintaining and operating the Navy Department and the Naval Service. It finances purchase or manufacture of all stores, supply, and services taken up in the Naval Stock Account.

The Naval Stock Account (NSA) is a holding account consisting of all general stores and supplies (GSK) which have been procured for the Navy, but not yet issued for use. Upon issue, the Navy is reimbursed from an appropriation.

The Naval Stock Fund (NSF) is established in such a manner that a cycle of operations may be carried out through a process of expenditures and reimbursement. The value of the NSF is represented by a combination of cash, stores, and other assets. That is to say, the total value remains the same in that the cash in the fund plus the value of the material assets always equal the total authorized amount of the fund.

Appropriations

The Appropriations Purchase Account (APA) represents material that has been procured and charged directly against an appropriation. The material is usually issued for general station use without charge to any monetary allotment. Payment for APA is made directly from an appropriation at the time of its original purchase. APA is an item of actual expense to the Navy at the time of procurement, but is carried in the APA until final issue is made, at which time it is charged against a Bureau control number for accounting purposes only, since payment from an appropriation has already been made.

Procurement

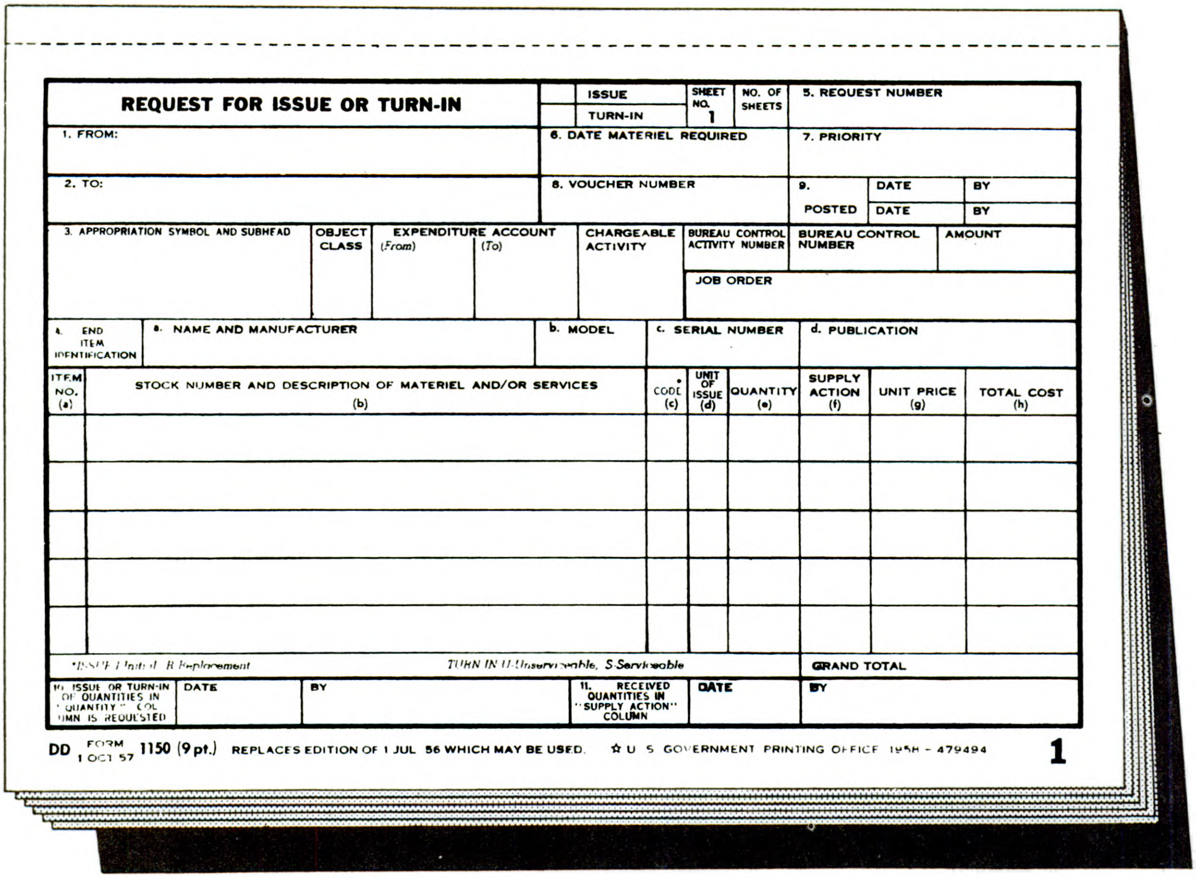
The procurement of material for a particular unit is authorized through established supply channels. Only by accurate ordering and complete information regarding the desired material can the GF be assured of obtaining the requested items. The currently used stub requisition (DD 1150) is shown in figure 1-10. In general, the form serves the two-fold purpose of issue and turn-in.

As an issue form, it can be used as a station requisition to

1. Request issue of material or services for final use providing there are funds available to cover the issue;
2. Request replenishment of shop store material; and
3. Request issue of material from shop stores.

As a turn-in form, the DD 1150 serves to

1. Return material for credit to shop stores; and
2. Return material for credit from an activity, shop stores, or department to regular supply department stores.



REQUEST FOR ISSUE OR TURN-IN

ISSUE
TURN-IN
SHEET NO. 1
NO. OF SHEETS
5. REQUEST NUMBER
1. FROM:
6. DATE MATERIEL REQUIRED
7. PRIORITY
2. TO:
8. VOUCHER NUMBER
9. DATE BY
POSTED DATE BY
3. APPROPRIATION SYMBOL AND SUBHEAD
OBJECT CLASS
EXPENDITURE ACCOUNT (From) (To)
CHARGEABLE ACTIVITY
BUREAU CONTROL ACTIVITY NUMBER
BUREAU CONTROL NUMBER
AMOUNT
JOB ORDER
4. END ITEM IDENTIFICATION
a. NAME AND MANUFACTURER
b. MODEL
c. SERIAL NUMBER
d. PUBLICATION

ITEM NO. (a)	STOCK NUMBER AND DESCRIPTION OF MATERIEL AND/OR SERVICES (b)	* CODE (c)	UNIT OF ISSUE (d)	QUANTITY (e)	SUPPLY ACTION (f)	UNIT PRICE (g)	TOTAL COST (h)

*ISSUE I-Initial R-Replacement TURN IN U-Unserviceable, S-Serviceable
GRAND TOTAL
10. ISSUE OR TURN-IN OF QUANTITIES IN "QUANTITY" COLUMN IS REQUESTED
DATE
BY
11. RECEIVED QUANTITIES IN "SUPPLY ACTION" COLUMN
DATE
BY

DD FORM 1 OCT 57 1150 (9 pt.) REPLACES EDITION OF 1 JUL 56 WHICH MAY BE USED. ☆ U S GOVERNMENT PRINTING OFFICE 1958 - 479494 1

Figure 1-10.—DD 1150.

Detailed and specific instructions governing the completion of the DD 1150 are contained in *BuSandA Manual,* Volume II, Chapter 2.

ALLOWANCE LISTS

The GFC in charge of supply in a missile activity should be aware of what supplies and in what quantities, both consumable and nonconsumable, he is legally entitled to for the maintenance of his equipment. Various lists, handbooks, manuals, and indexes are publicized which are essential references in the procurement of material and equipment. Certain of these publications are described in the following text.

Aeronautical Allowance Lists

Aeronautical Allowance List and Tables of Basic Allowance consist of the equipment and material (accountable, exchangeable and expendable) determined as necessary to place and maintain guided missile units (among many others) in a material readiness condition. As such, they are based on known or estimated requirements. They are not to be confused with catalogs or lists of material available in the supply system. All items of equipment and material allowed on a uniform basis and regularly required by or scheduled to be furnished upon initial commission or reactivation of activities or units are included in these lists.

Because missile activities are usually required to operate within the provisions of allowances, and because the lists provide so much supplemental information, it is necessary that senior GF personnel be familiar with a breakdown of the purposes of the various types as indicated in the following paragraphs:

1. Activity allowance lists contain the items of specialized and common material required by a specific activity upon commissioning. These are called "commissioning allowances" and are represented by the following types:

(a) Section A Allowance List (NavAer 00-35QA-1) contains both standard aeronautical material and General Stores (GSK) items for support of aircraft. Items contained in this list are held by the supporting activity in "Ready Issue" stock for issue as needed.

(b) Section G Allowance Lists (NavAer 00-35QG) contain allowances of shop and hangar equipment required by various maintenance activities to carry out their assigned responsibilities.

(c) Section K Allowance List (NavAer 00-35QK-1) itemizes the various types of publications and the quantities of each that have been determined to constitute the minimum requirements of the activities listed. Additional quantities which may be required in unusual circumstances may be requisitioned from supporting Publications Offices.

2. Initial Outfitting Lists contain the peculiar and/or common supply items required for maintenance support of a designated model of equipment for a period of 90 days. The following types of Initial Outfitting Lists are those most useful to missilemen:

(a) Section BR Initial Outfitting List (NavAer 00-35QBR-5) is a group of lists pertaining to guided missiles and pilotless aircraft. Applicable lists contain allowances for the maintenance or support of designated missiles for specified periods. The purpose of these lists is to prescribe maintenance-parts allowances for missile units deployed on operations; the items listed are issued as organizational property. The allowances are based on the experience of supporting activities and on usage data submitted to ASO and generally cover the expected life of the applicable missile.

(b) Section R Initial Outfitting Lists (NavAer 00-35QR series) are divided into two general types: those which have dash numbers less than 30; and those with dash numbers greater than 29. The former pertains to common categories of electronic material used in or with more than three types of electronic equipment; those of the latter type contain lists of major components and expendable parts of specific equipments. Of those with dash numbers less than 30, only four are in current use. List 4 covers standard electronic material including resistors, capacitors, and similar parts; list 5 pertains to electronic test equipment; list 6 is for aeronautical electronic accessories; and list 7 includes electronic vacuum tubes.

(c) Section U Allowance List (NavAer 00-35QU-1) itemizes standard handtool kits required for the maintenance support of aircraft.

(d) Section Z Initial Outfitting List (NavAer 00-35QZ-3) lists maintenance parts for special missile test equipment.

3. Table of Basic Allowance (TBA) (NavAer 00-35T series) is comprised of material for Special Mission Aviation Activities. These tables contain lists of shop equipment, common tools, and common supply stock items required by the activities to which they apply. An example is NA 00-35T-4, BuAer Allowance List, Air Launched Guided Missile Activities.

QUIZ

1. The scope of requirements for advancement in rate is wide and includes
   a. general and technical duties only
   b. military and special duties plus CO's recommendation
   c. professional qualifications only
   d. military and practical factors plus CO's recommendation

2. A record of practical factors is usually signed and kept by the
   a. division officer
   b. leading chief
   c. shop chief
   d. division chief

3. GF1 and GFC requirements differ from those of lower pay grades in that they include an effective knowledge of
   a. supervision, training, and administration
   b. military and technical skills
   c. supply and publications
   d. rules and regulations

4. Personnel administration is the science of getting things done and primarily involves
   a. personnel appearance
   b. personnel morale
   c. planning and coordination
   d. leadership and organization

5. Naval Ammunition Depots are responsible for
   a. overhaul and repair of guided missiles
   b. operational condition of guided missiles
   c. overhaul and repair of guided missile test equipment
   d. storing and issuing guided missiles

6. A GF1 or GFC assigned as a training petty officer primarily is responsible for
   a. missile availability
   b. procurement and supply
   c. technical training publications and individual training programs
   d. operation and maintenance of missile equipment

7. The present system of supply based on stocking spare parts by type has
   a. increased efficiency at a loss in economy
   b. decreased efficiency but improved economy
   c. increased efficiency and economy
   d. proved completely unsatisfactory

8. The Navy Stock Fund is a revolving fund within the
   a. Naval Stock Fund
   b. Appropriations Purchase Account
   c. General Fund
   d. Allowance Lists

9. The Navy Stock Fund is never used for procurement of
   a. general stores
   b. technical items
   c. supplies for operating the Navy Department
   d. services taken up in the Naval Stock Account

10. The Naval Stock Account is a/an
    a. revolving account
    b. holding account
    c. expense account
    d. account of issued supplies

11. The Appropriations Purchase Account represents material that is
    a. charged as an expense to the Navy
    b. paid from the Navy Stock Fund
    c. charged to the procurement account
    d. charged to the Navy before issue

12. Desired material may be obtained through supply channels by using the
    a. form DD 1150
    b. BuSandA Manual form
    c. Aeronautical Allowance Lists
    d. Naval Stock Account

13. The Commissioning Allowance List which lists maintenance parts for special missile test equipment is designated Section
    a. K
    b. U
    c. Z
    d. R

14. The section R Allowance List pertains to initial outfitting of
    a. handtool kits
    b. hangar equipment
    c. guided missiles and pilotless aircraft
    d. electronic material

15. In the Section R Allowance List, the designation 00-35QR-7 pertains to
    a. resistors and capacitors
    b. electronic test equipment
    c. electronic vacuum tubes
    d. aeronautical electronic accessories

16. A group of lists which pertain to guided missiles, and is based both on the experience of supporting activities and on usage data submitted to ASO, is the
    a. Section Z Initial Outfitting List
    b. Section BR Initial Outfitting List
    c. Table of Basic Allowance
    d. Section A Allowance List

17. The standard form, Record of Practical Factors, prescribed for all active duty personnel, is designated
    a. NavPers 760
    b. NavPers 10052
    c. NavPers 18068
    d. NavPers 18068 (Revised)

18. In the air-launched missile maintenance and logistic organization, rejects are sent to
    a. the manufacturer
    b. an O & R activity
    c. aircraft carriers
    d. a Naval Ammunition Depot

19. In the shipboard supply system, missile rocket motors are stowed
    a. in their shipping container
    b. after decanning
    c. in the arming area
    d. at the assembly area

20. Before attaching missiles to aircraft launchers, the launchers are usually checked by a/an
    a. visual inspection
    b. aircraft turnup
    c. special alining jig
    d. special purpose tester

21. A Section R Initial Outfitting List, designated NavAer 00-35QR and followed by a dash number greater than 30, pertains to
    a. list of common categories of electronic material used in, or with, more than three types of electronic equipment
    b. list covering standard electronic material
    c. list of major components and expendable parts of specific equipments
    d. list covering electronic test equipment

22. An important feature of the Manual of Qualifications for Advancement in Rating, NavPers 18068 (Revised) is
    a. the procedure by which it is revised
    b. it applies to all enlisted personnel of the Navy only
    c. it is not necessary for the trainee to consult the latest change in the Quals Manual
    d. the chances of a striker making his rate are included in a list which accompanies the qualifications

CHAPTER 2

TRANSISTORS AND THEIR APPLICATIONS TO MISSILES

The transistor is a relatively new device that uses some of the electrical properties of semiconductors to perform many of the functions formerly possible only with vacuum tubes. When employed in appropriate circuits, transistors can provide amplification, oscillation, pulse generation and counting, as well as performing many other functions including timing and gating.

The term transistor is coined from "TRANSfer" and "resISTOR." In commercial form, transistors are smaller, lighter, longer lived, more rugged, more efficient, and are potentially less costly than most vacuum tubes. Furthermore, they require no filament power, they draw comparatively small currents in operation, and they generate negligible amounts of heat. They possess the important additional advantage of instant warmup, and hence consume no standby power.

The guided missileman may expect to see a gradual introduction of the transistor in the equipment he is called upon to repair and maintain. Although few details concerning specific devices have been officially released, the transistor is becoming increasingly important in military equipment. It is obviously well suited for guided missile applications. And its characteristics make it desirable for use in proximity fuzes, miniature teletype and communications systems, radio and radar equipment, in compact airborne computers, and in many other systems in which light weight, small size, and reliability are important considerations.

The major objective of this chapter is to introduce the basic principles of transistor operation. Some of the theories associated with the transistor differ considerably from those applied to vacuum tubes and new concepts are needed in order to understand the somewhat unexpected performance. In this regard, it is suggested that the reader review chapter 1 of *Basic Electricity,* NavPers 10086; particularly those sections which deal with atomic structure.

Semiconductors

The operation of transistors depends upon the electrical properties of a class of substances known as semiconductors. This class is made up of solid materials which possess conductivities greater than that of a good insulator but less than that of a good conductor. The substances most frequently used as transistor materials are germanium and silicon to which certain impurities have been added. There are other materials which exhibit the required properties but these are not used as extensively as the two mentioned.

Transistors represent only a part of a large group of semiconductor devices. Included in this group are crystal diodes composed of germanium and silicon. Germanium diodes are often used as detectors, discriminators, and limiters; while the silicon type serves as mixers in many microwave devices. The old crystal radio receiver, employing a galena crystal and an adjustable "cat whisker" represents one of the earliest applications of semiconductor materials in radio circuits.

ELECTRONS AND HOLES IN SEMICONDUCTORS

The new concept associated with transistor operation involves two distinct process by which electric charges are conducted. Two kinds of current flow are present within the material of the transistor. One current is the familiar electron current, which is a drift of free electrons under the influence of an electric field. This current is called excess conduction, conduction by excess electrons, or simply conduction by electrons.

The second kind of current is called deficit conduction, or conduction by holes. This current takes place in materials in which the electrical bonds between the atoms are weakened by deficiencies of electrons, leaving "holes" in the bond structure. When a potential is applied across such material, free electrons within it jump progressively from hole to hole. The progress of the electrons gives rise to an apparent motion of holes, which move in a direction opposite to that of electron movement.

A familiar example of fluid flow which serves as an analogy of the apparent motion of holes in semiconductors is the movement of vapor bubbles in the liquid-filled columns seen on some types of juke box. In these, a drop of liquid is vaporized at the bottom of the tube. As the liquid above the bubble moves downward to fill the space produced, the vapor bubble rises. Thus the rise of the bubble is really caused by the downward motion of the liquid. Similarly, the flow of positively charged holes in germanium or silicon is accompanied by motion of negatively charged particles (electrons) in the opposite direction.

A hole in the transistor material is essentially the absence of an electron and hence is a region of positive charge; and since the holes move, their motion constitutes an electric current. This type of conduction, which is of primary importance in transistor action, occurs in materials composed of certain kinds of crystalline structure. To understand the hole concept more clearly, it is necessary to consider briefly the arrangement of the atoms making up the crystal and also the types of materials represented in typical examples.

ATOMIC STRUCTURE

An atom consists of a positively charged nucleus containing a fixed number of protons surrounded by an equal number of electrons. The latter are distributed in various orbits, each of which can contain not more than a fixed maximum number of electrons. When an orbit contains this maximum number, it is said to be complete.

In most atoms, the orbits near the nucleus are complete and only the outer orbit is incomplete. The nucleus, together with the innermost orbits, form a stable "ionic core" which has a positive net charge and which can be considered as remaining inactive as far as chemical reactions and electrical phenomena are concerned. The electrons of the outer orbits largely determine the chemical characteristics of the substance, the electrical conductivity, and the tendency of the material to enter into combination with other kinds of materials to form compounds.

CRYSTAL STRUCTURE

The valence, or combining power of the atom is dependent principally upon the number of electrons contained in the outer orbit. Germanium for example, has 32 electrons rotating about the nucleus of each atom. Twenty-eight of these are tightly bound to the nucleus, while the remaining four electrons are available for making valence bonds with other atoms. Hence, in most of its combinations, germanium exhibits a valence of four, or is said to be tetravalent. The silicon atom contains 14 electrons, four of which make up the outer orbit; and for this reason, silicon is similar to germanium in that it is tetravalent, and only four electrons in each atom are able to enter into chemical reactions.

Each of the four valence electrons of an atom of germanium or silicon form bonds with an electron from one of the four nearest atoms. These pairs of bonded electrons are commonly known as covalent bonds. They provide the forces that bind the atoms of the semiconductor and hold them rigidly in place to form a three-dimensional structure called a crystalline lattice. This same form of inner structure is characteristic not only of the semiconducting substances but also of many other kinds of materials including the metals.

The three-dimensional crystal lattice is illustrated in figure 2-1 in which the covalent bonds are represented as rods joining the atoms. Each bond is composed of two electrons, one contributed by a single atom so that each electron pair is shared by two nuclei. This relationship of the atoms is redrawn in two-dimensional form in figure 2-2 to show how each bond between adjacent atoms is made up of a pair of electrons with the result that a stable structure is produced.

GERMANIUM CHARACTERISTICS

The atomic arrangement shown in (A) of figure 2-2 represents pure germanium. Note that all the atoms are equidistant and that the cores of each pair of atoms are separated by a double-electron, or covalent bond. In this

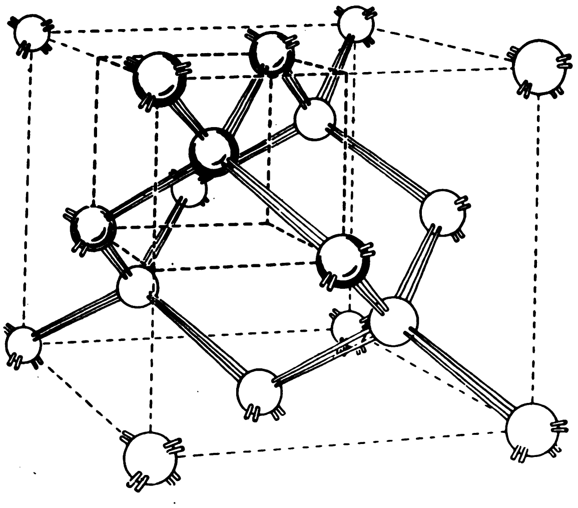


Figure 2-1.—Crystal structure showing covalent bonds.

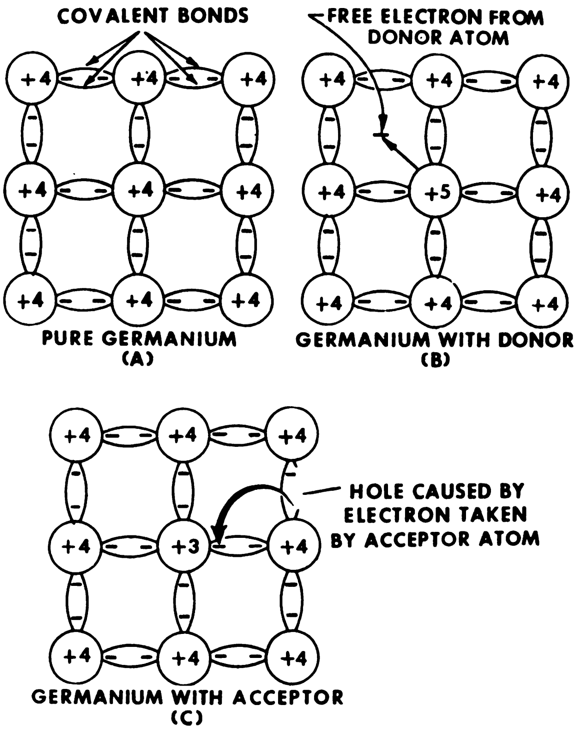


Figure 2-2.—Germanium with and without impurities.

state of the crystal structure, germanium behaves as a partial insulator. A condition of electrical equilibrium exists, and the forces of attraction and repulsion between the atoms are in exact balance. However, in germanium, because of thermal agitation which occurs at ordinary room temperatures, some electrons acquire sufficient energy to break the covalent bonds and become free. These electrons are then able to move throughout the crystal structure and are available for conduction. As a result of this action, germanium (or silicon) is classified as a semiconductor rather than as an insulator.

In addition to thermal agitation, other physical conditions may affect the flow of current. These conditions include radiation from a strong light source or the presence of applied electric fields. It is the response of the material to the latter condition which makes the transistor usable in many electronic circuits, where formerly vacuum tubes only were used.

The drawings in figure 2-2 serve to make clear the two types of current upon which transistor action depends. If a sample of germanium or silicon is placed in an electric field, two modes of conduction occur. First, the ejected electrons drift in a direction determined by the polarity of the applied potential. The second type of current results from the motion of electrons in breaking away from one band to fill up the hole caused by the absence of an electron in an adjacent band. The hole may thus be considered as migrating from one atom to another through the material and as acting effectively as though it were an electron with a positive charge. Thus the migration of the holes of the structure resembles a current, or flow of positively charged particles. The hole current, together with the electron flow, constitute the two types of conduction in the material.

DONORS AND ACCEPTORS

The modification of the crystal structure to increase conduction and to provide two kinds of semiconducting materials can be illustrated by the drawings in (B) and (C) of figure 2-2. If a small amount of impurity material such as arsenic is mixed with the pure germanium (or silicon), an application of potential to the resulting structure then produces more electron current than hole current. This results from the atomic arrangement shown in (B). Each atom of arsenic contains five valence electrons; and when introduced into the germanium structure, the arsenic atom displaces an atom of the pure material, forms four covalent bonds with adjacent atoms, and provides an extra electron which is unbonded. This electron is then free to move through the material under the influence of applied fields and thus to conduct.

A semiconductor with excess electrons, such as germanium with an arsenic impurity, is called an n-type substance because the principal current carriers are electrons. Arsenic, phosphorus, antimony, and other impurities, when added to germanium or silicon make n-type semiconductors and are called donors.

The crystalline structure produced when an impurity such as boron is added to germanium can be indicated by the drawing in (C) of figure 2-2. This type of structure has an excess of holes, a result of the fact that the boron atom has only three valence electrons. This is not enough to complete the valence bonds; and therefore, for each boron atom that displaces a germanium atom, there is one bond which has a hole, or a deficiency of one electron. The hole in the bond can be filled by an electron from an adjacent bond; but this leaves a hole where the electron was situated originally, so that the hole moves and thereby contributes to the conductivity of the substance.

Semiconductors with an excess of holes are called p-type materials because the principal current carriers are positive holes. These materials are formed by adding trivalent elements such as boron, aluminum, gallium, or indium. These elements, when employed as impurities to make p-type semiconducting materials, are called acceptors.

By the use of both acceptor and donor materials, transistors are capable of controlling the flow of both positive and negative charges. It should be noted that, generally speaking, this is in contrast to the fundamental action of vacuum tubes, which depend only upon electrons for conduction.

THE P-N JUNCTION AS A SEMICONDUCTOR DIODE

Consider next the physical construction of one of the basic devices upon which transistor operation depends. This is the p-n junction, which is made up of an n-type and a p-type semiconductor in close proximity. This type of junction, which is illustrated in figure 2-3, is made from a single piece of material (a single crystal); but the materials on each side of the junction have different electrical characteristics.

The p-n diode element may be fabricated by either of two methods, one of which is used to produce the alloy (or fusion) junction and the other the grown junction. Both processes are involved operations since the atoms of the two crystalline structures forming the junction must be in proper alinement; and it is not feasible to make a satisfactory junction by simply joining two pieces of material mechanically.

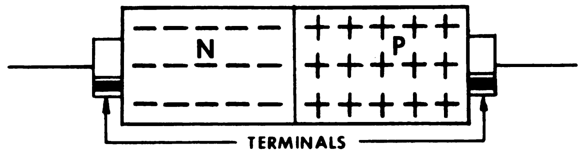


Figure 2-3.—A p-n junction.

The fused junction is made by placing a small "dot" of indium on a wafer of n-type germanium and causing the two to fuse through an application of heat. When the fusion occurs, p-type germanium is produced in proximity to the fusion area. Hence, there is a p-n junction between this region and the remainder of the n-type wafer.

A grown junction is produced by adding impurities to molten germanium or silicon (called the melt). The required structure then results as the crystal forms from the cooling material. At the start of crystal growth, an impurity of one type is added; and near the middle of the growing process, an impurity of the opposite type is added. In this way, a junction is formed when the melt is changed from a p-type to an n-type (or vice versa), resulting in a crystal with p-material at one end and an n-type material at the other.

FORWARD AND REVERSE BIAS

When a d-c voltage is applied to the p-n element, the current flow that takes place depends upon the polarity of the applied potential. If the negative terminal is attached to the n-type material, free electrons move away from the terminal and flow toward the junction. In a similar manner, the holes in the p-type material migrate from the positive terminal and move toward the junction. There they combine with the free electrons of the n-type substance. Under this condition, the junction permits a free exchange of positive and negative charges, and a comparatively large current flow takes place. An applied voltage of this polarity (negative terminal to n-type, positive to p-type) is referred to as forward bias.

If the polarity of the applied voltage is reversed so that the positive terminal is attached

to the n-material and the negative to the p-type, action of a different type results. Holes in the p-material are then attracted away from the junction and flow toward the negative terminal. Electrons in the n-material are attracted to the positive terminal of the source. The flow of charges continues until the fixed charges of the immovable impurity atoms balance the forces of attraction and stop the flow. An applied voltage of this polarity is referred to as reverse bias. In this condition, a high resistance results; a relatively small amount of current is present; and a comparatively strong electrostatic field is developed across the junction. The small reverse current flowing with reverse bias is called reverse saturation current.

Conduction of charges through the p-n diode is governed by the strength of the electrostatic field, called the barrier field, which is present at the junction. This field results from the proximity of fixed positive and negative charges provided by the donor and acceptor atoms in the transition region.

The barrier field should not be conceived as an actual physical object but rather as a "potential hill," the height of which is proportional to the amount of energy required to conduct an electron across the junction. With reverse bias, all mobile holes and electrons are effectively removed from the junction; and the fixed charges of the stationary p- and n-type atoms produce an opposing field which causes the junction to approach the condition of an insulator.

With forward bias the field strength is modified by the presence of mobile charges so that the junction offers less opposition to current flow. In general, the applied potential indirectly regulates the strength of the barrier field, and this in turn determines the conduction through the junction.

Construction and Characteristics of Transistors

TERMINOLOGY

In the short history of transistor development, certain fundamental terms and concepts have evolved and have become generally accepted for purposes of description and explanation. The principal terms, together with the symbols usually associated with them, are given in the following list. These are employed throughout the remaining pages of this chapter which deal with transistor characteristics and applications.

Symbol	Term
α	. . . Current gain (current-amplification factor)
β	. . . Base current gain
I_b	. . . Base current
I_c	. . . Collector current
I_{co}	. . . Collector cutoff current
I_e	. . . Emitter current
r_b	. . . Base resistance
r_c	. . . Collector resistance
r_e	. . . Emitter resistance
V_b	. . . Base voltage
V_c	. . . Collector voltage
V_e	. . . Emitter voltage
R_i	. . . Input resistance
C_c	. . . Collector capacitance
$f_{\alpha_{co}}$	. . . Alpha cutoff frequency

The conventional circuit symbols used to represent transistors in schematic diagrams, together with additional terminology and symbolic representation, are included in appropriate parts of the sections which follow.

THE JUNCTION TRANSISTOR

The information given in the previous section pertaining to the p-n junction is applicable to the junction triode transistor illustrated in figure 2-4. This transistor consists essentially of two p-n junctions. It is constructed of three layers of semiconductor materials and represents the basic member of the class of junction transistors.

The center layer (fig. 2-4) is a wafer of either n- or p-type material; and the outer layers are always of the opposite type. Transistors of this sort are designated by the composition of the layers. For example, one constructed with a center layer of p-material (and hence with outer layers of n-material) is called an n-p-n transistor. Also, a junction triode containing a center layer of n-material is known as a p-n-p transistor.

One of the outer layers of the triode transistor is designated the emitter; while the other outer layer is called the collector. The center layer is called the base. From each of the three elements, low-resistance leads are

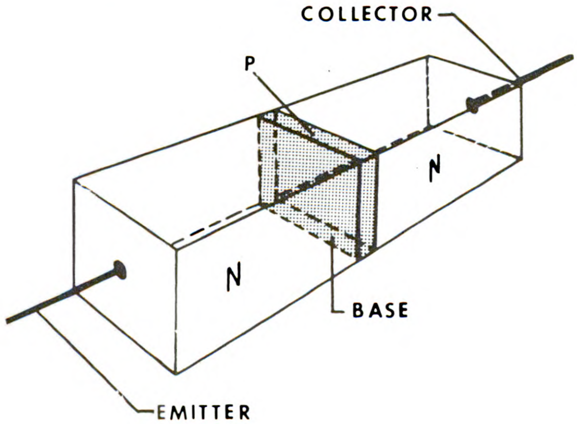


Figure 2-4.—A junction triode transistor.

brought out by which connections can be made to external circuit components. The complete transistor assembly is usually sealed in a suitable casing to provide ruggedness and freedom from atmospheric contamination. A typical example of the physical construction employed can be illustrated by the drawing in figure 2-5. The leads from the emitter, collector, and base layers are brought through an insulating material and attached to pin connections. This permits the transistor to be plugged into a socket in a manner similar to that used with most electron tubes.

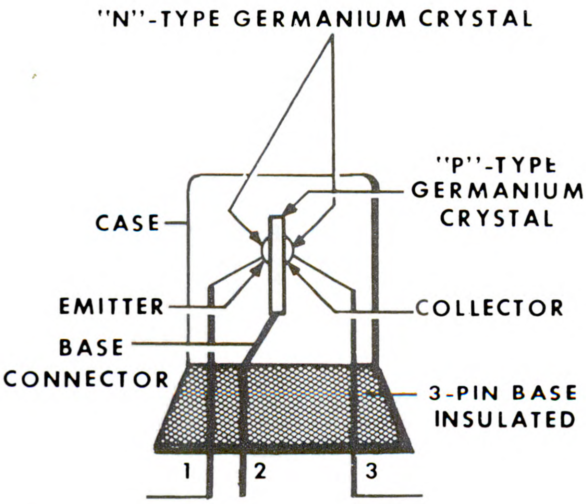


Figure 2-5.—Hermetically sealed junction transistor.

Schematic Symbols

The schematic symbols generally used to represent the two types of junction triode transistors are shown in figure 2-6. The base is symbolized by a straight line. The emitter and collector layers are represented by lines drawn at angles to the base symbol. The line corresponding to the emitter contains an arrowhead, which also serves in most instances to identify the transistor type. An arrowhead directed into the base line indicates a p-n-p; while an arrowhead directed away from the base indicates the n-p-n type. (Caution should be observed in this regard during replacement or repair procedures, since in some schematic drawings the same symbol is employed for both types.)

It should be noted that the arrowhead in the schematic symbol also indicates the direction of positive current flow when forward bias is applied to the emitter-base junction. Positive current, in this case, is defined as hole current and is in a direction opposite to that of electron flow.

Bias Polarities

An important general rule concerning the d-c operating bias is illustrated by the drawings in figure 2-6. The rule can be stated as follows: The emitter-base junction is biased in the forward direction; the collector-base junction is biased in the reverse direction. Consider (A) of the figure, which shows the proper polarities for the n-p-n transistor. The n-type material of the emitter is biased negatively with respect to the p-type base. The collector, on the other hand, is made positive with respect to the base.

The polarities employed with the p-n-p transistor are shown in (B) of figure 2-6. To bias the emitter-base junction in the forward direction, the positive terminal of the bias supply is attached to the emitter and the negative terminal to the base layer. The collector-base junction must be biased in the reverse direction; hence, the positive terminal of the bias battery is connected to the base and the negative terminal to the collector.

In both types of junction triodes, the principal current flow takes place between the emitter and the collector layers. In the n-p-n type, for example, this current consists of electrons moving from the emitter to the collector. The electrons leave the emitter and flow into the base; and since the base layer is quite thin, most of the charges continue towards the collector because of the strong electric field existing at the collector junction.

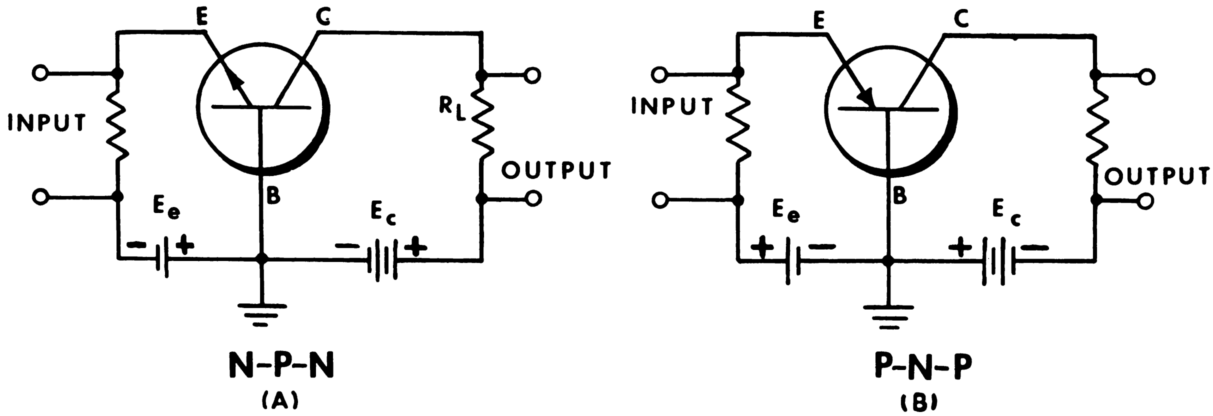


Figure 2-6.—Basic transistor schematic symbols.

In both the n-p-n and p-n-p types, the base currents are very small since they consist of the comparatively few electrons that combine with holes in the base material. The value of the base current is determined largely by the difference of the emitter and collector currents. Thus, in general, the collector current in the junction transistor is less than the emitter current, differing from it by an amount equal to the total base current.

It should be noted that the collector current is controlled essentially by the emitter current rather than by the collector voltage. Variations in emitter current are produced by adding a small a-c signal in series with the emitter bias. As a result of this procedure, the collector current then varies in proportion to the input signal.

If the emitter voltage is reduced to zero, a small amount of collector current then flows through the high resistance of the collector junction because of the reverse bias voltage. This current is referred to as the cutoff current (I_{co}), or reverse saturation current.

Alpha

One of the most essential of the transistor characteristics listed at the beginning of this section is the quantity called alpha, a parameter used to express current gain. Transistor alpha is defined as the ratio of the change in collector current to the corresponding change in emitter current, when the collector voltage is held constant.

The alpha of a given transistor can be determined by means of characteristic curves of the type shown in figure 2-7. Employing these as an example, assume that the collector voltage, V_c, is held constant at 12.5 volts. As can be seen from the curves, if the emitter current is changed from an initial value of 1 milliampere to 3 milliamperes, there is a corresponding change in collector current from 0.92 to 2.90 milliamperes. Applying these data in the formula

$$\alpha = -\frac{\Delta I_c}{\Delta I_e} \text{ gives}$$

$$\alpha = -\frac{-1.98}{2.00} \quad \text{or}$$

$$\alpha = 0.99.$$

The negative sign in the numerator of the second equation indicates a current flowing in a direction which is reverse of that assigned as the positive direction.

Collector Capacitance and Transit Time

There are several factors which have limited the use of the transistor. One of the most important of these has been the comparatively poor response to high frequencies. In the typical transistor, this results principally from two quantities: the capacitance of the collector junction, and a fairly large value of transit time. The latter is the interval required for charges to be carried through the base layer as they flow from emitter to collector.

Capacitance exists at both the emitter and collector junctions; but that of the collector usually has the greater effect. Under forward bias conditions, the emitter junction capacitance may be rather large; however, it may be

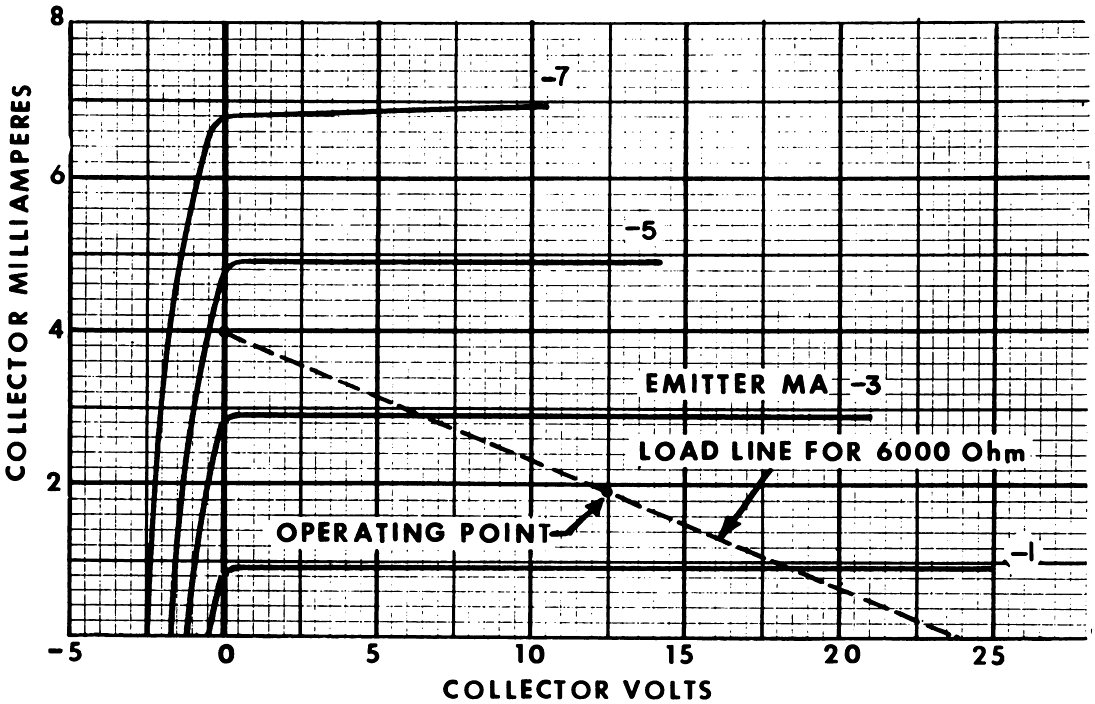


Figure 2-7.—Characteristic curves for junction transistor.

neglected since it is effectively shunted by the low resistance of the emitter circuit. On the other hand, although the collector is biased in the reverse direction and has a rather low capacitance, it cannot be ignored because of the high impedance normally employed as a load element in the collector circuit. The collector capacitance, C_c, plus the stray capacitances of the external circuit, are in shunt with the high-impedance load. The effect of the total shunt capacitance is to decrease the effective load impedance as frequency is increased so that the power output falls off at the higher frequency ranges.

The second major factor limiting frequency response is the transit time. The hole current within the semiconductor material results from the motion of electrons; however, the mobility of holes in the material may be considerably less than that of free electrons. The relatively slow velocity of the hole current is a contributing factor in limiting frequency response.

In the event that the transit time of a current carrier is equal to the period of one cycle of input frequency, the positive half of the input cycle may still be "within" the emitter-collector area at the time the negative half of the cycle "enters." In this case, the flow of current carriers resulting from both halves of the cycle being present simultaneously may result in cancellation; and in this event, the current gain would be reduced to zero. This condition represents the maximum effect, or the limiting case. In general, the alpha value changes with frequency, increasing as the frequency decreases. For this reason, alpha is usually defined as a ratio of changes in current at a particular frequency, a value often employed being 270 cycles per second.

An idea that is closely related to the transit-time theory of frequency limitation is the conception of straight-line current flow. Ideally, the lines of flow of the current carriers within the transistor material are straight-line paths. But in actuality they are circuitous rather than straight and resemble somewhat the curved lines of the fringing flux in the magnetic field between the two poles of a horseshoe-shaped magnet. The curvature of the current paths is a factor tending to increase transit time and hence to reduce the upper limit of the operating frequency range.

Since transistors are operated at various frequencies, some method of designating the maximum efficient operating frequency is required. It has been decided that this maximum shall be taken as the frequency at which the

alpha is reduced to 70.7 percent of the normal rated value. The symbol for this point is $f_{\alpha_{co}}$, known as alpha cutoff frequency.

An interesting fact with regard to the transit-time effect is the associated phase shift. At the alpha cutoff frequency, the phase difference of the output with respect to the input waveform is approximately 60 degrees. As in vacuum-tube circuits, the phase shifts occurring during amplification are generally undesirable since they tend to reduce circuit efficiency.

Junction Tetrode Transistors

Several types of junction transistors have been developed to improve the high-frequency response by partially overcoming the effects of transit time and collector capacitance. Among these are the junction tetrode type and the intrinsic-layer transistors which are illustrated in figures 2-8 and 2-9, respectively.

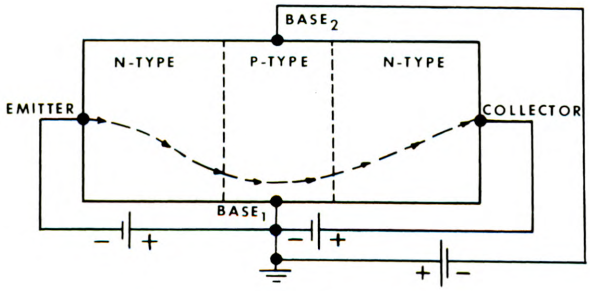


Figure 2-8.—A junction tetrode.

The tetrode transistor (fig. 2-8) is similar to the junction types discussed previously, except that a second connection is made to the base on the side opposite the normal connection. By applying a repelling bias to the second connection, the emitter-to-collector current is compressed into a small area near the normal base connection. This action permits a type of physical construction which has advantageous effects in reducing transit time and undesirable capacitance, thereby increasing the value of the alpha cutoff frequency.

The collector capacitance, C_c, is dependent upon the thickness of the base; and with triode construction, the base layer could not be made much thinner without making a sizeable increase in the capacitance. However, with a decrease in the cross-sectional area resulting from the repelling bias, the thickness of the base material may be reduced without causing too great a change in C_c. Decreasing the thickness has the advantage of decreasing the transit time, which as stated above, has considerable importance in frequency considerations. Thus, the junction tetrode is characterized by an increased alpha cutoff value as compared with the typical triode transistor.

Intrinsic-Layer Triode Transistors

The n-p-i-n junction transistor shown in figure 2-9 differs from the junction triode in that it contains an additional layer of I-type material, or intrinsic material. This usually consists of either germanium or silicon in extremely pure state. The intrinsic layer contains an equal number of donors and acceptors; and when it is inserted between the base and collector materials, it effectively separates them in such a way that the collector capacitance is reduced.

The base layer is made very thin and is composed of high-conductivity material to reduce the value of the base resistance. The intrinsic material has low conductivity so that a considerable voltage-drop is developed across it; however, this is usually offset by making the collector bias voltage high enough to compensate for the additional I-R drop.

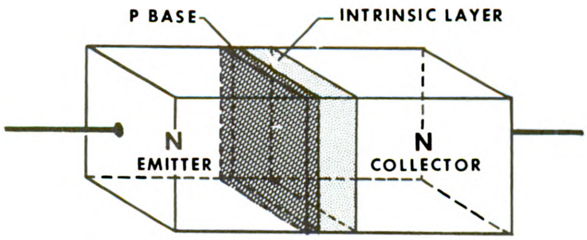


Figure 2-9.—An n-p-i-n junction transistor.

The counterpart of the n-p-i-n junction transistor (fig. 2-9) is the p-n-i-p type. Like the junction tetrode, both varieties of intrinsic-layer transistors have the advantages, when compared with triodes, of lower values of C_c; higher ratings as to alpha cutoff frequency; and improved high-frequency characteristics.

THE POINT-CONTACT TRANSISTOR

The various types of junction transistors discussed above make up one of the two major classes of these devices. The other class contains the members of the point-contact

group. Historically, the point-contact transistor was developed prior to the junction types; but because of the greater possibilities for improved performance, the latter are largely supplanting the point-contact transistors in many kinds of applications. The following discussion of this class is confined mainly to a brief description of the basic physical construction and the principal characteristics of operation.

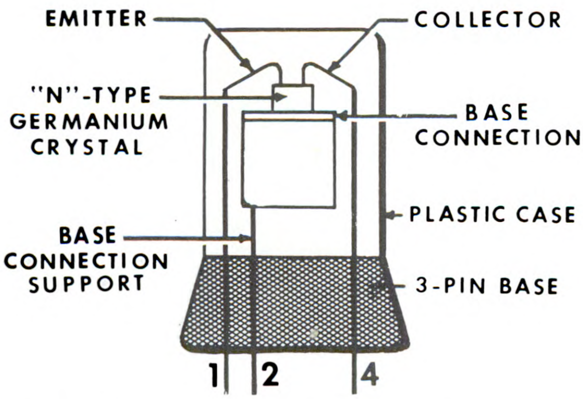


Figure 2-10.—Construction of the point-contact transistor.

The type of construction employed in most point-contact transistors is indicated in figure 2-10. The emitter and collector connections are made through the pointed ends of very small electrodes spaced a few thousandths of an inch apart. The electrodes make contact with the base material, a small wafer of germanium or silicon, either of the n- or the p-type.

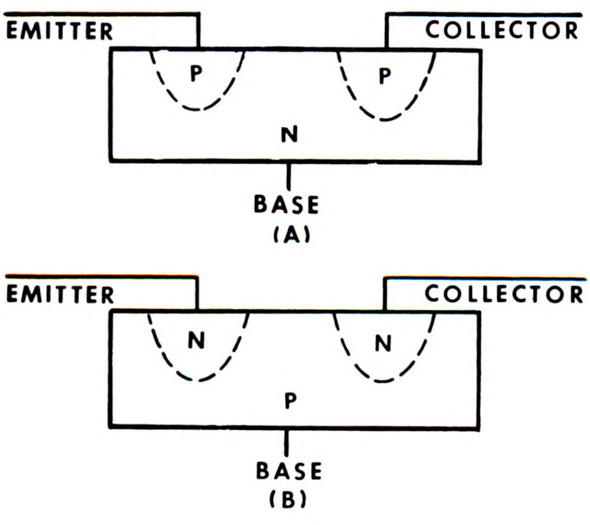


Figure 2-11.—Electrode arrangement of a point-contact transistor.

The operation of point-contact transistors is based on the process of hole and electron injection. If a pointed metal electrode is made to contact a p-type material; and if the metal is made negative with respect to the material; then the point contact supplies electrons to the base.

This process, called electron injection, is the counterpart of hole injection in which electrons are drawn off from an n-type base by means of a positively charged pointed electrode.

The fundamental arrangement of the electrodes with respect to the materials in the base wafer is indicated by the drawings in figure 2-11. In both the n- and p-type bases shown, there are small amounts of material of the opposite type situated just under the points at which the electrodes contact the base. These materials, which are essential in the action of electron (or hole) injection, are produced during the manufacture of the transistor and result from a process called forming. This process is essentially one of passing surges of current between the electrodes and base material.

The result of the forming process with a base composed of n-type germanium is shown in (A) of figure 2-11, which indicates that small quantities of p-type germanium are deposited under the electrodes. Similarly, if the base is of p-type material, the forming process produces n-type germanium at the points of contact, as shown in (B) of the figure. Thus, from the standpoint of chemical composition, the n-type point-contact transistor closely resembles the p-n-p junction; while the p-type point-contact is similar to the n-p-n junction transistor.

There are certain basic similarities as well as differences in the operation of the point-contact compared with the junction transistor. One of the important similarities concerns the polarities of the bias voltages. As in the junction type, the emitter of the point-contact type is biased in the forward direction, or the direction of high conduction. Similarly, the collector-to-base bias is in the reverse direction.

An important difference in the characteristics of the point-contact and junction types lies in the alpha values typical of each. As in the junction, the emitter current of the point-contact controls the collector current; but in the latter type, the ratio of changes in the two currents is comparatively high. Thus, the alpha, or ratio of change of collector to

corresponding change in emitter current (with collector voltage constant) is usually in the neighborhood of 2 to 4. This is in contrast with the same ratio for the junction, in which the alpha value never exceeds unity.

The exact reason for the high current gains exhibited by the point-contact transistor is not well understood; but one widely accepted theory suggests that the effect is due to an alteration which takes place in the physical structure of the material during the forming process. As a consequence of this alteration, the barrier field at the collector-base region is lowered; and the flow of charges is such that several holes (or electrons) are activated for each hole (or electron) reaching the collector.

Unlike the junction transistor, the collector voltage of the point-contact has considerable effect on collector current. This can be shown by a set of characteristic curves such as those in figure 2-12. Study of these reveals that there is an appreciable slope above the knee of each curve, indicating that there is considerable change in the collector current as the collector voltage is varied and emitter current is held constant. This property is in contrast with the behavior of the junction type, the corresponding curves of which are illustrated by the example given in figure 2-7.

The high values of alpha associated with point-contact transistors make it possible for these units to possess negative resistance when connected in certain circuits. This property is useful for generating sustained oscillations; and a circuit employing it is discussed and illustrated (fig. 2-22) in a subsequent section of this chapter.

POWER LIMITATIONS

Both junction and point-contact transistors are subject to certain conditions that limit the power handling capability and make the problem of heat dissipation of primary importance. These conditions include the existence of a critical temperature of operation and the action known as impurity diffusion.

As previously stated, thermal agitation at ordinary room temperatures causes some electrons in the semiconductor material to acquire sufficient energy to break the covalent bonds and become free. As the temperature increases, the number of free electrons increases correspondingly; and if their number

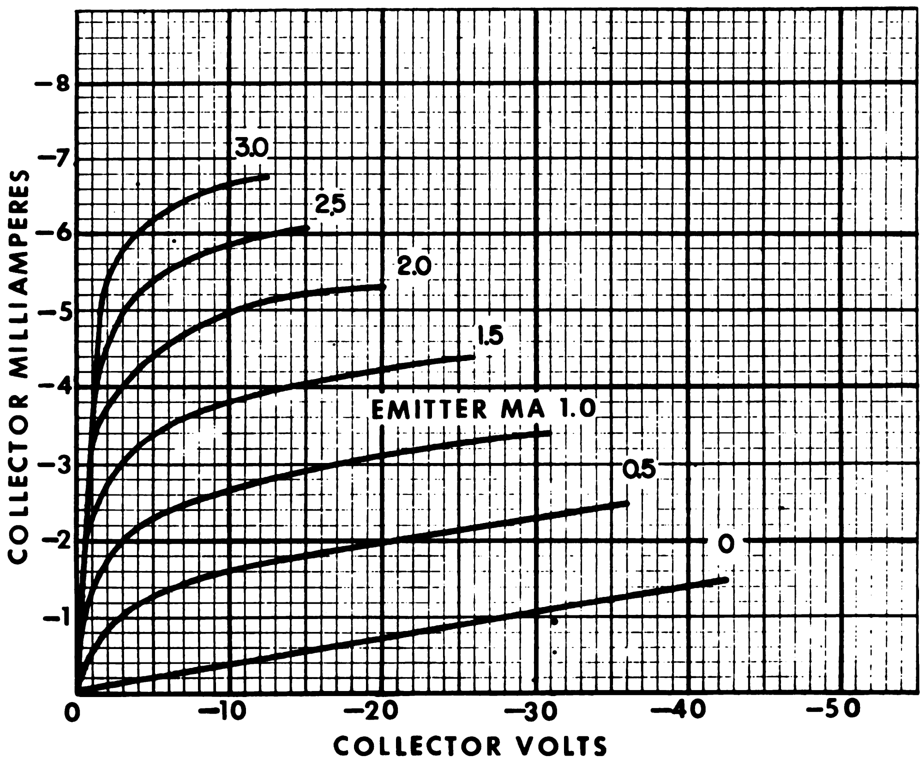


Figure 2-12.—Point-contact transistor characteristic curves.

becomes excessive, even intrinsic material undergoes a sharp increase in conductivity. As a result, germanium has a negative temperature coefficient so that a given sample shows a marked decrease in resistance with an increase in temperature.

At a certain critical temperature, usually about 200° F. for most samples of germanium, the number of free electrons becomes excessive. The conductivity then rises rapidly, and the large number of thermally agitated electrons causes a heavy, uncontrolled current flow that nullifies transistor action.

If the operating temperature exceeds the critical value, impurity diffusion occurs. In this condition, thermal agitation is so excessive that the barrier fields break down and impurity atoms move through the material. This action results in permanent destruction of the transistor.

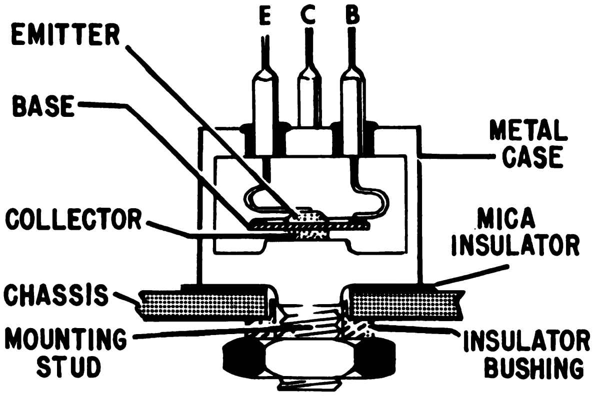


Figure 2-13.—Cutaway view of a typical high-power transistor.

In view of the effects of temperature on transistor operation, provision for adequate heat dissipation is a requirement in circuit design and chassis layout. Figure 2-13 shows the method employed for this purpose in a typical high-power transistor. As in any other type of conductor or semiconductor, current flow results in heat losses, which in the case of the transistor, are largely dissipated at the collector junction. With considerable amounts of power, it is possible that heat may be generated faster than the junction can dissipate it, so that an additional method of removal is needed. This means is provided in the unit illustrated by an electrode attached to the container case. The electrode conducts heat from the junction to the casing, which serves as a large radiating surface capable of releasing heat at a higher rate than would be possible with the junction acting alone.

In circuits which permit the casing to be operated at ground potential, it is attached to the chassis, which then serves as a heat sink, or an element capable of absorbing heat energy. In these cases, the chassis then serves as an aid in heat dissipation which permits the transistor to be operated at higher power levels. In circuits which require the container to be operated at a potential above ground, it is usually mounted on a mica insulator as illustrated in figure 2-13.

Because of the effects of heat on transistor action, it is necessary to take into consideration the ambient, or room, temperatures to which transistorized equipment is subjected. In general, high ambient temperatures reduce the ability of the heat sinks to take on additional heat, reduce the rate of dissipation, and thereby effectively lower the power levels at which the transistors can be operated.

Power Gain

One of the major differences between transistor and vacuum-tube circuits is in the power gain provided by individual stages. The principal feature of the transistor is its current controlling ability. Although the current gain of a single stage may be actually less than unity, there may be considerable gain in power. In stages which employ the collector circuit as the output and the emitter as the input, the fact that the collector current is approximately equal to the emitter is useful. The collector current flows through a high-impedance load so that the power developed at the output represents a considerable gain over the input power, which is applied to the low-impedance emitter circuit.

Thus each stage of a cascaded series of transistors contributes an increase in power; and the total gain of all the stages may be quite great. In the operation of vacuum-tube equipment, on the other hand, the final or output stage alone is usually employed as a power amplifier; and the preceding stages as a rule serve as voltage amplifiers. As with electron tubes, transistors can be connected for push-pull operation or as single-ended power amplifiers, and can operate in class A, B, or AB. Typical values of power gain vary with the circuits involved; and with junction transistors, gain figures may range from about 440 to 6,600.

Noise

As in the operation of vacuum tubes, transistors generate noise energy which limits the sensitivity of the circuit, or its ability to respond to low-level input signals. Noise is caused in transistors principally by random variations in the carrier currents when crossing the junctions. An additional source of undesirable noise is the random division of emitter current between the collector and base circuits.

The noise factors of typical junction transistors are lower than those of most point-contact types, although both compare unfavorably with vacuum tubes in this respect. The noise factors of junction transistors are reduced upon reduction of collector voltage; and experiments have shown that the quantity of noise produced tends to fall off as the frequency of the applied signal is increased.

Basic Transistor Circuits

In this section a number of basic circuits containing transistors are illustrated and discussed. These include transistor R-C and transformer-coupled amplifiers, typical control amplifiers, and oscillator circuits. Most of the arrangements considered are based on the junction transistor, although one of the basic oscillators employs a point-contact type.

To understand the operation of the basic circuits, it is necessary first to consider the three fundamental ways in which a triode transistor can be connected and to establish the similarities and differences between the elements of the transistor and the corresponding elements of vacuum tubes.

The three fundamental circuit connections with the triode transistor are the common-base, the common-emitter, and the common-collector arrangements. The word common in these terms refers to the element of the transistor that appears in both the input and output circuits; however, in some cases, the word grounded is used instead.

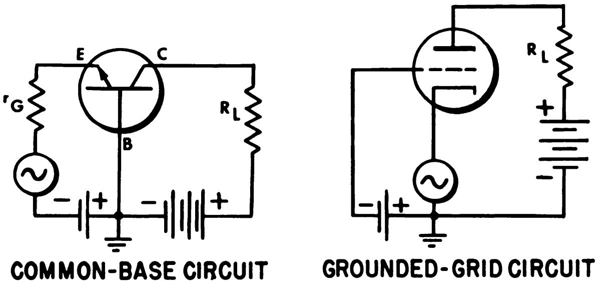


Figure 2-14.—Common-base transistor amplifier with vacuum-tube equivalent.

THE COMMON-BASE CIRCUIT

Figure 2-14 shows the common-base transistor circuit and the vacuum-tube equivalent, the grounded-grid amplifier, the operation of which is discussed in *Basic Electronics*, NavPers 10087, chapter 4. Comparison of the two circuits reveals that the transistor base is comparable to the vacuum-tube grid; the emitter corresponds to the cathode; and the collector is similar in function to the plate in that it is connected to the load resistor or output element.

There is an important difference in the two circuits (fig. 2-14) with regard to the no-signal voltages, or bias potentials. The electron tube normally operates with the input circuit (cathode-to-grid) biased in the reverse, or high-impedance direction; while the transistor bias is such that the emitter-base junction (input) is biased in the forward, or low-impedance direction. The output circuit of the tube, the plate circuit, is biased in the forward direction; while the transistor collector-base junction is biased in the reverse, or high-impedance direction.

The transistor schematic symbol used in figure 2-14 identifies the unit as an n-p-n type; however, if the transistor were of the p-n-p type, the general rule of bias polarity would apply equally well. The emitter-base junction would be biased in the forward, the collector-base junction in the reverse directions. With p-n-p transistors, this would be achieved by reversing the terminals of the d-c bias batteries shown in the figure.

The common-base transistor amplifier provides voltage and power gain. Input a-c signals are applied in series with the emitter bias, causing the emitter current to vary about the no-signal value. The total emitter current consists of two unequal parts: the smaller current flows through the emitter-base junction; the larger component constitutes the collector current, which flows through the collector-base junction, through the load

resistor, and returns to the emitter circuit through the collector power supply.

The collector current follows the variations of the emitter current and develops a comparatively large voltage drop across the high resistance load, R_L. As in the equivalent grounded-grid amplifier, the transistor amplifier is characterized by in-phase relation of the output and input voltages. As the emitter voltage swings negative, there is an increase in emitter current and a corresponding increase in the value of the collector current flowing in the load resistor. With the polarity of the applied collector voltage shown in figure 2-14, this results in a negative-going output signal voltage. Positive excursions of the emitter voltage, on the other hand, produce positive-going values of output voltage.

The junction transistor connected in the common-base circuit provides power gain primarily because the output, or collector, current flows through a high-impedance load. Hence, the power delivered to the load element is substantially greater than the power consumed in the low-impedance input circuit, even though the output current is slightly less than the input current.

Current Gain

The current gain of the common-base amplifier is less than unity when junction transistors are employed. The gain is given quantitatively by the emitter-collector alpha of the transistor, which is determined by the ratio of changes in collector to changes in emitter current. In equation form, the current gain can be expressed by the following relations:

$$\text{Current gain} = \alpha = -\frac{\Delta I_c}{\Delta I_e}$$

in which ΔI_c and ΔI_e indicate changes in collector and emitter current, respectively. Suppose that a given signal applied to the emitter causes an increase in the emitter current of 1 milliampere and a corresponding increase in collector current of 0.98 milliamperes. These figures, when substituted in the equation give the result:

$$\text{Current gain} = \alpha = -\frac{0.98}{-1} = +\ 0.98.$$

The use of the negative signs in the equation above is in accordance with a widely accepted definition for "positive currents" in transistor elements. The definition can be illustrated by figure 2-15: the heavy arrows

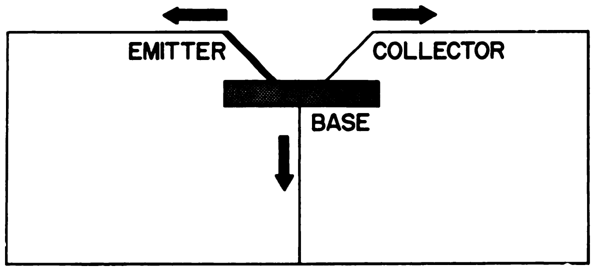


Figure 2-15.—Assigned directions for positive currents.

indicate directions of electron flow which by agreement are to be designated as positively directed currents. Electrons flowing with the arrow associated with a particular element are said to comprise a positive current, which is then given a positive sign when substituted in an equation or formula. Similarly, electron flow directed against an arrow is considered as a "negative current" and the corresponding symbol is preceded by a negative sign.

The simple computation in the preceding equation involves an expression containing two negative signs and therefore gives a figure for current gain which is a positive quantity. The negative sign preceding the fraction is part of the definition of emitter-collector alpha, which is essentially a ratio of currents having opposite signs. The 1-milliampere change in emitter current is given a negative sign since it represents an increase in a current which is considered negative in accordance with the current convention illustrated in figure 2-15.

In many cases, transistor characteristic curves show emitter currents as negative values to indicate flow in a direction opposite the assigned positive direction. In general, the signs of the currents are useful principally in circuit analysis and for most practical purposes may be ignored.

The characteristics of the common-base amplifier circuit employing a junction transistor may be summarized by the following list: low input impedance; high output-circuit impedance; no voltage phase reversal between input and output; current gain less than unity; good stability; and moderate power gain.

THE COMMON-EMITTER CIRCUIT

The common-emitter transistor circuit and the vacuum-tube equivalent, the grounded-cathode amplifier, are illustrated in figure 2-16. As in the basic circuit previously described, there are fundamental similarities in

the two amplifiers: the transistor base is equivalent to the electron-tube grid; the emitter is similar to the cathode; and the collector compares with the plate. The input elements of the transistor amplifier are the base and the emitter, the latter being common to both input and output circuits. Small input signal voltages injected between base and emitter cause collector-current and output-voltage variations which are large compared with the input. Typical voltage gains with junction transistors may be as high as 550.

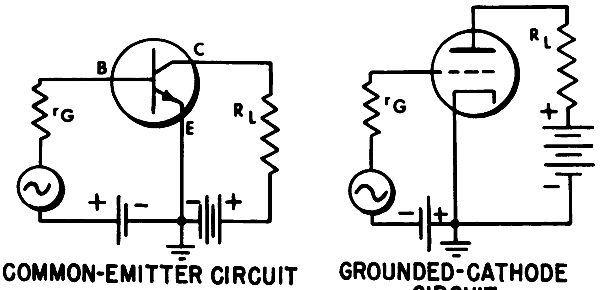


Figure 2-16.—Common-emitter transistor amplifier and vacuum-tube equivalent.

The actions of the two circuits (fig. 2-16) are similar in that each introduces a phase reversal of the output voltage with respect to the input. This process in the transistor occurs in the following way. When the input voltage applied to the base swings positive, there is a resulting increase in base current and also in emitter current. The emitter current increase causes a corresponding increase in collector current, which flows through the high-resistance load element. With the collector polarity shown in the figure, the increased voltage drop across the load is such that the output voltage (collector-to-ground) swings less positive, or in the negative direction.

When the input signal is negative-going, the base, emitter, and collector currents decrease; the voltage developed across the load resistor diminishes and the output voltage swings in the positive direction. Thus, there is an inherent phase reversal of the output voltage with the common-emitter transistor which is not present in the actions of the other two basic circuit arrangements.

Current Gain

One of the advantages of the common-emitter circuit arrangement is comparative simplicity, so that in some cases, it is possible to employ a single d-c supply connected from emitter to ground which serves to bias both the input and output circuits. Another important advantage lies in the fact that it provides large current gains, typical values of which are in the order of 25 with junction transistors. This contrasts very favorably with the common-base amplifier, which has a gain of less than unity with the same type of transistor.

The principal reason for the large value of current gain arises from the fact that the current flowing in the input circuit, the base current, is equal to the difference of the emitter and collector currents. And if the latter two are very nearly equal, the ratio of output to input current variations is then quite large.

The absolute value of the common-emitter current amplification is given by the following expression:

$$\text{Current gain} = \frac{\Delta I_c}{\Delta I_b}$$

in which I_c and I_b are collector current and base current, respectively.

It is desirable to express this fraction in terms of alpha, the ratio of changes in the collector and emitter currents. This can be done by setting I_b, the base current, as equal to the difference of the emitter and collector currents:

$$\text{Current gain} = \frac{\Delta I_c}{I_e - \Delta I_c}$$

where I_e is the emitter current. This fraction can then be modified without changing its value by dividing both numerator and denominator by ΔI_e, thus,

$$\text{Current gain} = \frac{\dfrac{\Delta I_c}{\Delta I_e}}{1 - \dfrac{\Delta I_c}{\Delta I_e}}.$$

It will be recalled that the ratio of collector to emitter current changes appearing in the fraction above is the numerical value of the transistor alpha, so that the formula can be stated as

$$\text{Current gain} = \beta = \frac{\alpha}{1 - \alpha}.$$

In this form the fraction is designated by the character beta (β), which symbolizes the base-current amplification factor, or current gain. It can be seen from the equation for beta that

the closer the alpha value approaches unity (or as the collector current approaches the value of the emitter current), the greater is the current amplification of the circuit.

Input and Output Impedances

As in any other electrical device, maximum energy is transferred to the input of the transistor amplifier when the input impedance matches the impedance of the driver. Similarly, if the transistor amplifier is to develop maximum power in the load, the resistance of the latter must match the impedance of the transistor output circuit.

Typical values of input impedance in the common-emitter junction transistor are considerably different from those of the common-base circuit when the same transistor is employed in both. In the former, average input impedances range from about 650 to 700 ohms, as compared with a typical value for the common-base of 90 ohms. The internal impedance of the collector circuit with a common-emitter connection is usually about 60,000 ohms. The same value for the junction transistor in the common-base circuit is approximately 500,000 ohms. Thus, as a general rule, the load resistance values suitable for developing maximum output power are lower for the common-emitter compared with the common-base amplifier.

With small input signals, the values of power gain realized in the common-emitter junction amplifier are in the order of 6,600, or 36 decibels (db). With common-base junction units, typical power gains are considerably less: about 440, or 26 db, being a representative figure.

High-Frequency Response

One of the disadvantages of the transistor circuit shown in figure 2-16 is a comparatively poor response to signals of high frequency. Since both the base and collector voltages vary under signal conditions, there are effective variations in the base thickness, in the transit time, and in the collector capacitance. As a result, the action of the amplifier displays considerable sensitivity to changes in signal frequency; and compared with the common-base amplifier, the gain begins to fall off at a lower point of the frequency range.

Summary

The characteristics of the common-emitter junction amplifier can be summarized by the following list of major features: signal-voltage phase reversal between the input and output; highest current gain factor of the three basic connections; moderate input impedance; moderate values of output impedance; comparatively low response to high frequencies; and high values of power gain.

THE COMMON-COLLECTOR CIRCUIT

In figure 2-17 the third basic transistor connection, the common-collector circuit, is shown with the equivalent vacuum-tube amplifier, the cathode follower. As in the preceding transistor connections, the emitter functions in a way similar to the cathode; and in the arrangement illustrated, the emitter circuit contains the load element across which the output signal is developed. The base is again equivalent to the vacuum-tube grid; while the collector, which is analogous to the plate, is operated at ground potential insofar as a-c signal voltages are concerned.

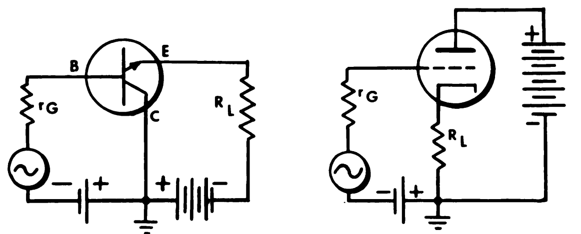


Figure 2-17.—Common-collector transistor amplifier and vacuum-tube equivalent.

The fundamental characteristic of the transistor circuit (fig. 2-17) involves the input and output impedances. The input circuit contains the base-collector junction, which is biased in the reverse, or high-impedance direction. Hence, as in the cathode follower, the input circuit has a high value of impedance; while in the forward-biased emitter, the output provides a low-impedance circuit. A-c signals coupled to the base circuit are reflected in the low-impedance output; and as in the cathode follower, the voltage gains possible with the common-collector arrangement are less than unity, or 1.

The ratio of a-c currents in the emitter (output) and base (input), however, are such that with junction transistors, large current gains can be achieved. The gain, or amplification, in this case is

$$\text{Current gain} = \frac{-\Delta I_e}{\Delta I_b}$$

where I_e and I_b are emitter and base currents. (The negative sign is used in accordance with the convention for positive directions given in figure 2-15.)

Again, the current gain can be expressed in terms of the alpha value by equating I_b to the difference in corresponding changes in the emitter and collector currents in the equation above and by then dividing both numerator and denominator by ΔI_e. When this is done, the expression for current gain becomes

$$\text{Current gain} = \frac{-1}{1-\alpha}$$

in which the symbol alpha indicates the emitter-collector current-gain characteristic.

The formula reveals that the current gain is large if alpha is less than but nearly equal to 1, as in the case with most junction transistors. With alpha less than unity, the ratio is negative, which means that there is a phase reversal of the output when considered in accordance with the arbitrarily assigned directions for positive current flow. It is interesting to note that with alpha values greater than unity, as can be the case with point-contact transistors, the gain is less than 1 and is positive, indicating no phase reversal of current. In this respect, the performance of the point-contact transistor compares unfavorably with the junction type: current gains in the former average about 0.7 as against approximately 25 for junction transistors.

The main characteristics of the common-collector transistor amplifier are: low output impedance; high input impedance; moderate to high power gain; a voltage gain of less than unity; no signal voltage phase reversal between input and output.

In the preceding discussions, the characteristics of junction transistors have been the principal subjects of interest. In the following pages, typical circuits employing these units are considered which illustrate their applications in audio amplifiers, in test equipment circuitry, and in oscillators.

JUNCTION TRANSISTOR AMPLIFIERS

The Transformer-Coupled Circuit

Transistors are often used to provide high-gain audio-frequency amplifications. An example is given in figure 2-18, a schematic diagram showing a p-n-p junction transistor connected in the common-emitter arrangement and employed as a class-A type of audio power amplifier. Among the basic features are the method of coupling and the provisions made to insure circuit stability.

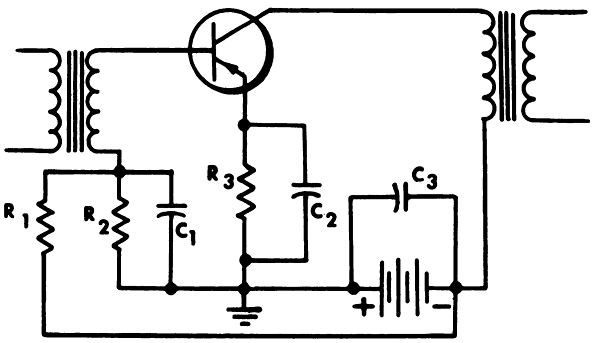


Figure 2-18.—Transformer-coupled transistor amplifier.

As indicated in figure 2-18, audio transformers are used to couple input signals into the base-emitter circuit and output signals from the collector-emitter circuit to the load. The low-impedance input circuit is matched to the driving circuit by means of the step-down input transformer; while the output transformer has a step-up turns ratio to match the high-impedance collector circuit to the following circuit.

The operation of the transistor depends largely upon the collector bias voltage and the emitter current. It is desirable that the collector bias voltage remain substantially constant and that the emitter current and collector cutoff currents remain largely unchanged either by replacement of the transistor or by changes in internal emitter resistance. The latter change might result from variations in temperature which affect the basic operation of the transistor.

Consider first the bias-voltage supply. A single battery provides the required d-c potentials in the circuit shown in figure 2-18. The voltage drops developed across R_1 and R_2 are applied to the collector and emitter, respectively, so that the collector is made

negative and the emitter positive with respect to the base. In order to keep the collector bias relatively constant, it is necessary that the bias battery have a very low internal resistance. If so, the terminal voltage and hence, the collector bias, will then undergo only slight changes as a result of variations in current drain.

The emitter bias circuit, on the other hand, requires high resistance to make the emitter current independent of changes in emitter internal resistance. This is supplied by R_3, a resistor with a large value compared with the internal resistance of the emitter junction. When placed in series with the emitter, the value of R_3 then largely determines the total resistance of the emitter circuit; and the emitter current becomes relatively unaffected by emitter-resistance variations.

Changes in the resistance of the emitter junction may occur as a result of transistor replacement since no two units have exactly the same values of internal resistance. The internal resistance may also change radically in the operating condition due to heat dissipation. The effects of either of these on the emitter current are minimized by the large constant value of the series resistor. In addition, it tends to stabilize the value of the collector cutoff current, I_{co}. The voltage drop across R_3 tends to make the emitter negative with respect to ground and thus is a factor in the emitter bias. Should I_{co} increase suddenly as a result of heat, the increase in current flowing through R_3 then increases the voltage drop, which in turn, effectively reduces the potential of the forward biased emitter, thereby reducing the collector current.

Capacitors C_1, C_2, and C_3 (fig. 2-18) effectively bypass audio voltages to ground. C_1 and C_2 also reduce any tendency of the circuit to go into oscillation as a result of coupling between the output and input circuits. The selection of values for the circuit components is made to insure stable operation and to provide maximum gain of small signals in applications requiring considerable power gain.

R-C Coupled Amplifiers

An example of a transistor voltage amplifier for audio signals is illustrated in figure 2-19. The common-emitter circuit permits the use of a single battery as a bias supply, the operation of which is similar to that in the preceding example.

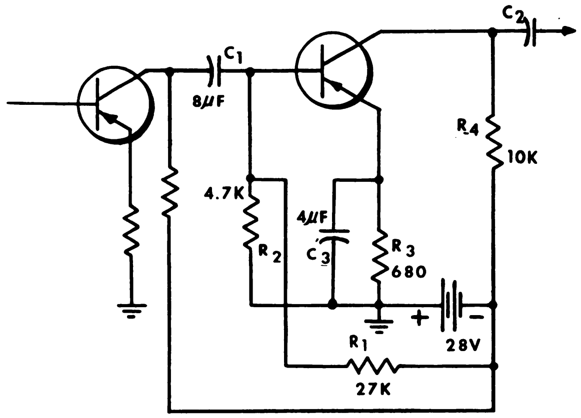


Figure 2-19.—Resistance-capacitance coupled transistor amplifier.

Since the principal consideration in the R-C coupled circuit is voltage amplification, the input signal is developed across resistor R_2 which has a large resistance value compared with the input resistance of the transistor. The high resistance draws small amounts of current but develops large signal-voltage values compared with the voltages produced by the transformer secondary in the power amplifier (fig. 2-18).

The R-C amplifier contains a stabilizing resistor, R_3, which is bypassed to audio frequencies by capacitor C_3. Capacitors C_1 and C_2 serve to couple a-c signals and to block d-c potentials. The capacitance values must be such that the capacitive reactances are low compared with the input resistance when the circuit is operating at the lowest frequency for which it is designed. In general, this requires high values of C, which requires, in turn, capacitors of large physical sizes. However, the low voltages applied reduce the allowable voltage ratings of the capacitors and permit units of comparatively small physical dimensions to be employed. Note that resistor R_2 is not bypassed since a capacitor placed in parallel would tend to short input signals to ground.

Cascaded Transistors

By connecting several transistor circuits in consecutive stages, or in cascade, large voltage or power gains can be obtained with good stability. In the present state of transistor development, the common-emitter arrangement is most frequently employed in

cascaded stages since it provides large amounts of gain with comparative simplicity of circuitry.

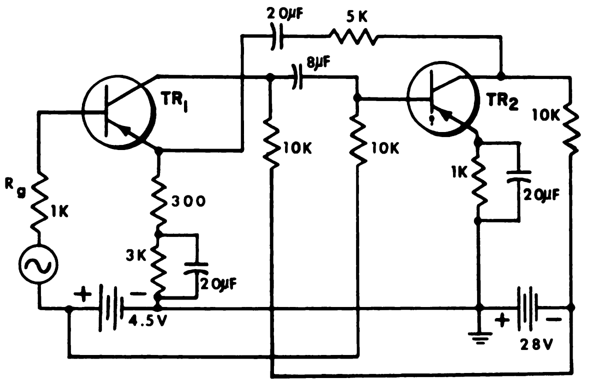


Figure 2-20.—Cascaded common-emitter transistor circuits.

The stages shown in figure 2-20 are characterized by medium input and output impedances. The operation of each common-emitter transistor is in accordance with that of the basic circuit described previously. The frequency response of the stages illustrated, however, is improved by the use of negative feedback.

The feedback circuit consists principally of the 5K resistor and the 20-microfarad capacitor through which a portion of the output of TR_2, the stage shown at the right, is fed back to the emitter of TR_1. When a negative-going signal is applied to the base of TR_1, there is a resulting positive-going voltage produced at the output of the first stage because of the phase reversal of the common-emitter circuit. This voltage is coupled to the base of TR_2 where it is again amplified and shifted in phase as it appears at the output of the collector circuit. The feedback circuit picks off a fraction of the negative-going output voltage from TR_2 and couples it back to the emitter of TR_1 which is thus driven negative as the base swings negative. The feedback voltage, which is smaller in amplitude than the input base voltage, effectively reduces the input signal and hence produces the partial cancellation required for degenerative feedback.

Positive-going voltages applied to the base of TR_1 result in the same sequence of action but with reversed polarities. The effect of the feedback circuit is to lower the overall gain of the amplifier but also to improve stability, to increase the response to frequencies at the upper portion of the operating range, and to decrease distortion.

Radio-Frequency Amplifiers

The high-frequency characteristics of transistors discussed in preceding sections are limiting factors when transistors are employed for radio-frequency amplification. In these applications, special circuit arrangements are usually required.

With r-f signals of medium frequency, for example, common-emitter to common-emitter cascaded stages are often used because of the voltage-gain values possible with this arrangement. This circuit requires neutralization, particularly at the higher range of frequencies, to prevent instability and oscillation resulting from coupling through the collector-base capacitances. Neutralization may be accomplished by providing an R-C series feedback loop from the base of one amplifier stage to the base of the preceding stage. Interstage coupling in this type of circuit is usually provided by transformers.

TRANSISTOR APPLICATIONS IN MISSILE TEST EQUIPMENT

The transistor circuits shown in figure 2-21 are representative of transistor applications in certain types of missile test equipment used to check the minimum amplitudes of a-c signals. The voltages applied at the input of the circuit may be considered to be those produced in the missile. The general purpose of the test device in this case is to check the voltage amplitudes to determine if the missile control section is operating properly. For example, if a given input signal is of a certain specified value, the relay RL_1 is then energized; the GO light burns; and the indication is given that the corresponding missile circuit is functioning properly.

To analyze the operation of the circuits illustrated in figure 2-21, assume that a potential of 6 volts is applied across potentiometer R_1, which is a calibration resistor that can be adjusted so that the relay is energized when the input voltage is 5 volts, r.m.s., or more.

Transistor TR_1 is a common-collector stage in which the common element is grounded to a-c signals by C_2. The input voltage is developed across R_2 and applied to the base of the first transistor. The output is developed across R_3. The operation of TR_1 is similar to that of a cathode follower in that the voltage gain is less than one and the output impedance is low.

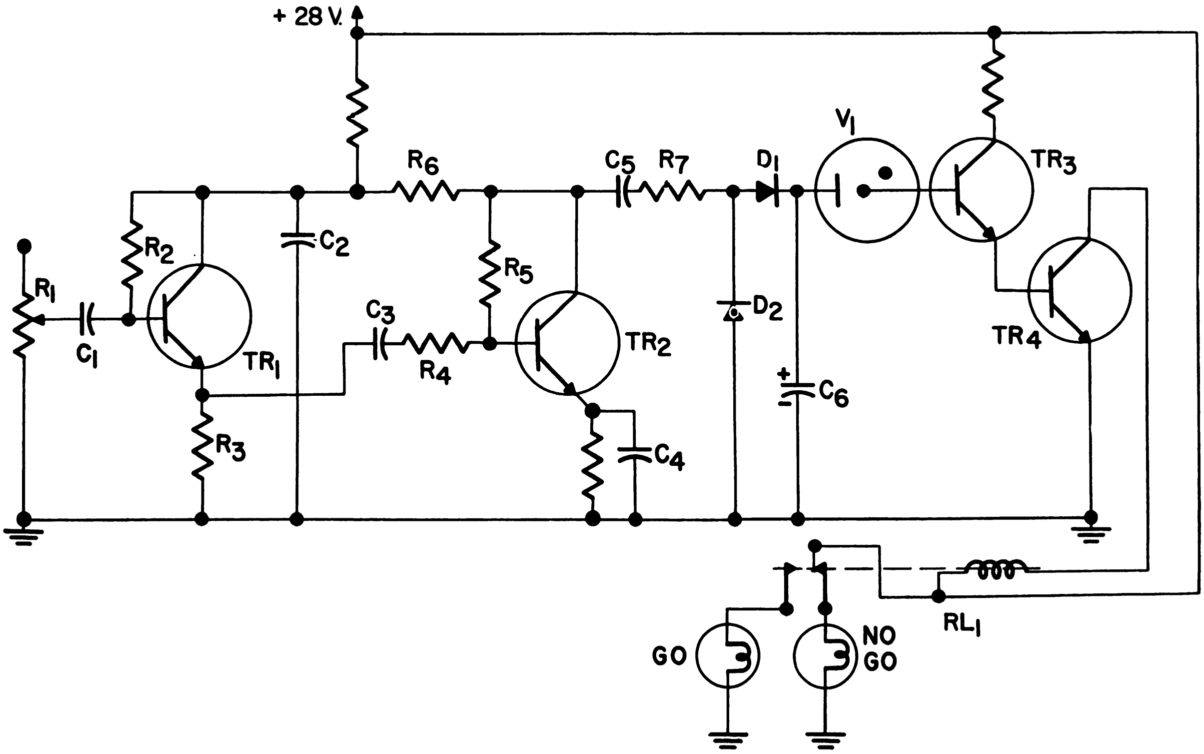


Figure 2-21.—Transistor amplifier and trigger circuits.

The signal voltage is coupled from the emitter of TR_1 through C_3 and R_4 to the base of the second stage, TR_2. This is a common-emitter circuit in which the emitter is held at a-c ground by means of C_4. The signal voltage at the base of TR_2 is developed across R_5; and the output which appears at R_6, is coupled through C_5 and R_7 to rectifiers D_1 and D_2

Transistor TR_2 is analogous to a grounded-cathode vacuum-tube amplifier with high voltage gain. The positive portion of the output a-c signal, when applied to the junction of D_1 and D_2 causes the former to conduct with the result that C_6 is charged to a value almost equal to the peak value of the voltage wave. The remaining half cycle is virtually shorted to ground by the rectifier during the entire negative portion of the cycle.

The gaseous regulator tube, V_1 will not conduct until the voltage applied to the terminal reaches the ionization potential. When this occurs, a positive potential is applied to the base of TR_3, causing this stage, together with transistor TR_4 to conduct. Conduction in TR_4 effectively grounds the upper end of the coil of relay RL_1, which closes the contact attaching the 28-volt supply to the GO lamp. If the original input voltage from the missile control circuit under test is insufficient to initiate the sequence described above, the relay remains unenergized and the NO-GO lamp burns to indicate unsatisfactory circuit conditions.

TRANSISTOR OSCILLATORS

To design a circuit that will oscillate, it is necessary to include (1) a device that provides amplification, (2) a means of controlling the output frequency, and (3) a feedback system for transferring energy from the output back to the input in proper phase relation. Oscillations are produced in vacuum-tube circuits by feeding back a portion of the signal in the plate circuit to the grid circuit in a way that aids the grid signal, thereby providing regenerative action. The required amplification results from the basic action of the tube; and tuning elements (one or more L-C combinations or a quartz crystal) are employed to control the frequency of the output signals.

Both junction and point-contact transistors can be used as amplifying devices in oscillator circuits. The junction transistor functions in

these applications similarly to a tube; and for every basic vacuum-tube oscillator, an equivalent junction transistor circuit may be devised. The point-contact transistor, however, has a special property which makes it very suitable as an oscillator circuit device. Under certain conditions, the point-contact base exhibits the property of negative resistance; and because of this, the transistor itself can provide the regenerative coupling between the output and input circuits so that no external feedback arrangement is necessary

The Negative-Resistance Oscillator

The point-contact circuit employing negative resistance is considered here in somewhat greater detail than the junction-transistor oscillators which follow since the former type has no vacuum-tube equivalent. The operation depends upon the basic characteristics of the point-contact transistor. In this type, the alpha value is always greater than one, which means that the a-c component of collector current is greater than the corresponding a-c component in the emitter circuit, typical ratios being 2.5 or slightly less. The base current is equal to the difference of the collector and emitter currents.

The property that provides the regenerative feedback lies in the "base resistance," the resistance of the germanium between the base terminal and the active portion near the emitter and collector points.

The basic action can be illustrated by the schematic shown in (A) of figure 2-22. Assume that the positive forward bias has just been applied to the emitter terminal. The emitter current begins to flow, passing through the base resistance. As a result of the emitter action, the collector current rises rapidly; and it, too, flows through the base resistance.

The collector current develops a voltage drop across the base resistance in such polarity as to partially neutralize, or cancel, the voltage drop produced by the emitter current. As a result, the latter increases and this in turn causes a further increase in the collector current. The buildup of collector current proceeds until it is limited by the number of available current carriers in the semiconductor material near the collector point.

Decreases in emitter current result in the converse action: the collector current falls off, reducing the voltage drop in the base resistance, which results in further decrease in

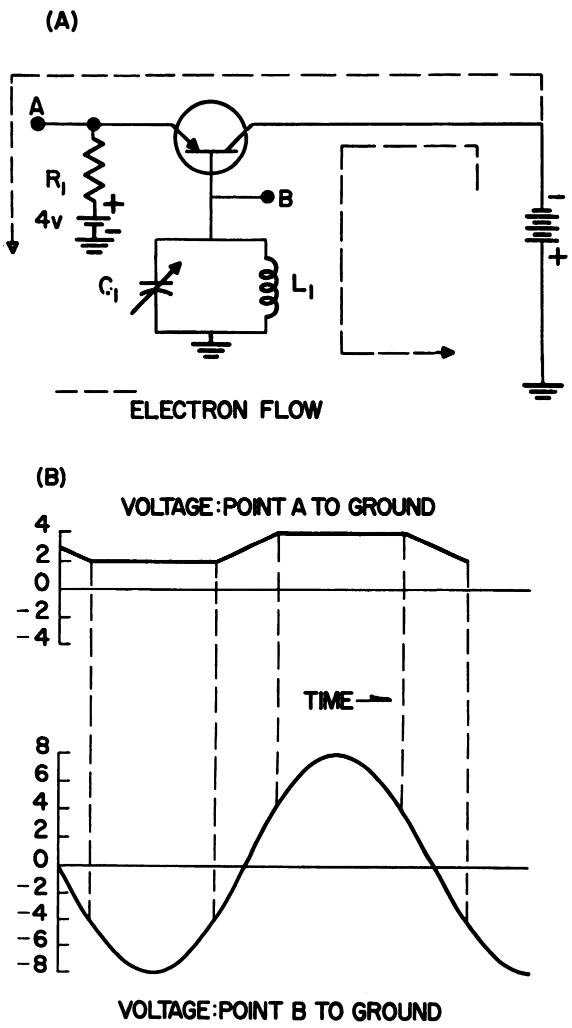


Figure 2-22.—(A) Point-contact negative—resistance oscillator; (B) voltage curves.

emitter current. Thus, the output signal tends to reinforce any change occurring in the input signal. This action is regenerative; and if the feedback is sufficiently great, the circuit will develop sustained oscillations in the L-C tuning circuit attached between base and ground.

When the circuit is oscillating, voltage variations represented by the waveforms shown in (B) of figure 2-22 appear at points A and B. As the voltage at point A decreases to plus 2 volts, the voltage at point B has changed to negative 4 volts. (The greater change occurs in the base circuit since the base-circuit impedance is very high compared with the impedance of the emitter circuit.) The emitter is then 6 volts positive with respect to the base;

and current saturation occurs within the transistor.

The voltage at point B continues to swing in the negative direction because of the collapsing magnetic field around L_1. When the field has collapsed completely, the charge on C_1 is such that the potential of the upper plate is 8 volts. The capacitor immediately begins to discharge through L_1, causing the voltage at point B to decrease in negative value; and when it reaches a value of about 4 volts, transistor current begins to decrease. As a result, the voltage at point A is increased as shown in figure 2-22.

Transistor current continues to decrease until the voltage at point B is equal to plus 4 volts; and at this time, there is no difference in potential between the emitter and the base elements and the transistor current is at cutoff.

It should be noted that the voltage change at point B is always greater than the voltage change at point A, a relation which increases the regenerative effect needed to sustain oscillation. When the transistor is at cutoff, the field about L_1 collapses, causing the voltage at point B to increase in the positive direction and reach the maximum value. At this time, C_1 is charged. When it begins discharging, the positive potential falls off; the emitter-base voltage swings toward the conducting state; and current begins to flow in the transistor, repeating the previous sequence of action. By following the waveforms in (B) of figure 2-22, it can be seen that the voltage at point B continues to change at the resonant frequency of the tank circuit, C_1 and L_1.

Junction Transistor Oscillators

Typical oscillator circuits based on junction transistors are shown in schematic form in figures 2-23 and 2-24. In the former circuit, the operation is similar to the tickler-feedback oscillator discussed in *Basic Electronics*, NavPers 10087, chapter 7. The crystal transistor oscillator illustrated in figure 2-24 employs a piezoelectric crystal as the frequency controlling element, which functions according to the general principles given in the same chapter of the basic text.

In the operation of the tickler-feedback oscillator (fig. 2-23), a portion of the a-c signal in the collector circuit is fed back in phase with the signal in the base circuit by transformer action. The input junction of the common-emitter transistor is biased in the forward direction by means of R_1 and C_1.

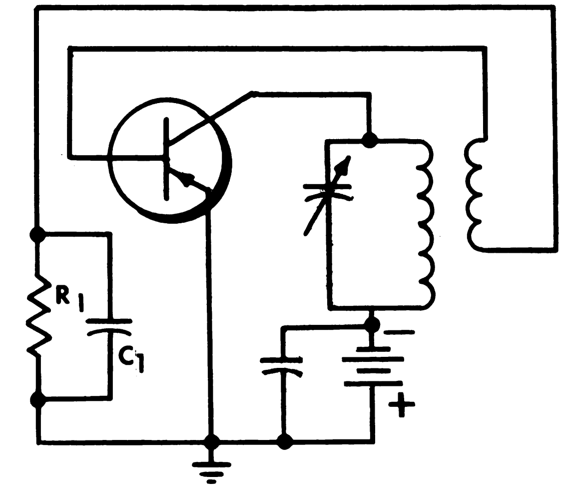


Figure 2-23.—Tickler-feedback oscillator.

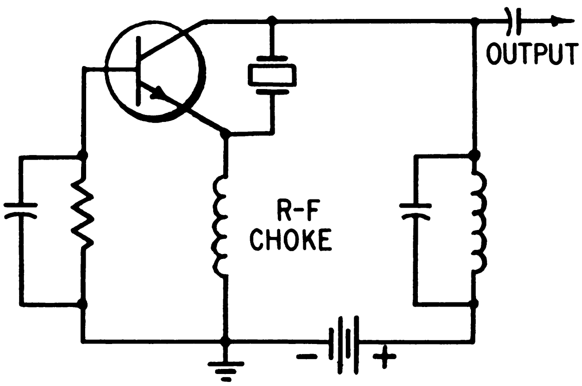


Figure 2-24.—Crystal controlled transistor oscillator.

A junction transistor is connected in the common-base arrangement in figure 2-24, which shows the crystal connected between collector and emitter elements. The crystal functions as a parallel resonant tank circuit and provides a frequency-sensitive device which couples energy from the output to the input circuits to give the necessary regenerative feedback.

Care and Servicing of Transistorized Equipment

Although transistors can be expected to operate indefinitely under normal conditions, they can be easily damaged as a result of abuse, overheating, or overload. And unless special precautions are used in maintenance, there is a possibility that transistorized equipment may be ruined. An example of special importance is the surface-barrier transistor which is employed in many types of Navy equipment. This transistor, which is designed for operation at high frequencies, has a construction that makes it very sensitive to overload; and considerable care should be exercised when applying test signals to or making measurements in equipment containing these units.

The general precautions observed when servicing devices containing semiconductor diodes should also be observed with transistorized components; and in addition it should be borne in mind that transistor circuitry is frequently more complex and hence demands more skill and understanding on the part of the technician. Miniature parts used in many kinds of transistorized units can be burned out by voltages supplied by signal generators and multimeters, even when the power supply is turned off. This means that one must not measure parts values indiscriminately, as has often been the procedure used with electron-tube circuits.

An additional factor which requires special care results from the fact that transistor circuits generally contain bypass and coupling capacitors of much lower voltage ratings than many of the devices for which conventional test sets were originally designed. Before applying any test signal or even a multimeter to a transistor circuit, the technician should first check the maximum allowable current, voltage, and power ratings of each transistor. The resistance of the transistor changes with the magnitude and polarity of applied voltages; and this should be taken into account when selecting maximum values of test signals during checkout.

Always remember that a simple slip can ruin many costly transistors and that when servicing equipment containing them, it is necessary to know the limitations of the units involved and to follow carefully the detailed instructions pertaining to the specific equipment. In addition to specific maintenance instructions, there are certain general precautions which should be observed in most cases. These are given in condensed form in table 2-1, which will be of assistance to the technician who is called upon to service transistorized equipment.

Table 2-1.—Precautions for avoiding damage to transistors while servicing circuits.

Basic Failure: Heat Damage

Cause: Transistor is subjected to high temperature.

Possible source of abuse	Suggestion to avoid abuse
Using soldering iron.	Disconnect circuit's power source and use mutual ground. Clamp wire with pliers between transistor and connection to keep heat away if possible. Use very hot, small iron (35 watts or less). "Get in fast" and "get out fast," before heat can travel into the transistor.
Permitting excessive temperature.	Keep equipment where temperatures are below 130°F. (Check transistor specifications if higher limits are needed.)

Table 2-1.—Continued

Basic Failure: Burnout or "Runaway"

Cause: Allowable power dissipation is exceeded in any part of the transistor.

Possible source of abuse	Suggestion to avoid abuse
Shorting out, shunting, or grounding the transistor input resistor with power applied, causing inadequate bias.	Use extreme care to avoid shorts or shunts. Insulate test prods to the tip. Do not connect test leads to transistor if ends of leads are free to short circuit. Use only insulated prods or keep the power off. Include d-c isolation (suitable capacitor) between signal source and transistor.
Connecting the collector voltage without the base bias voltage.	Avoid connecting transistors or plugging them into sockets unless the power supply voltages are off.
Using multimeter (battery) on the "low" resistance range.	Check on allowable currents and voltages for transistor elements. Restrict resistance measuring ranges to safe ones or use limiting resistances (series and parallel as necessary).
Shorting any parts that cause excessive power to be applied to the transistor.	Do not use a voltmeter of low resistance or other device that will radically affect circuit resistance or voltages, in either the base or collector circuits.
Using an ungrounded soldering iron, thus connecting leakage current into the transistor circuit.	(1) Do not solder, connect, or disconnect with voltages on transistor. (2) Ground iron tip (through shank) to transistor circuit ground, in a safe manner; use isolation (1:1) transformer, or use 6-volt iron.
Inadvertently connecting voltages or currents (such as radio interference filter current, or leakage from the power line, RF pickup, external batteries, power supply voltages or test oscillator voltages).	Ground chassis or cases using all necessary safety precautions. Reduce stray fields (use insulated shield, if necessary). Before connecting, check test lead voltage compared to that of transistor circuit with electronic multimeter (AN/USM-34), to assure low enough voltage. Do not connect low impedance device across equipment voltage or current supplies or loads.
Inducing current by magnetic field of a soldering gun (such as Weller, transformer type).	Do not use high-current-carrying conductor or soldering device near wiring.
Subjecting transistor to power line transients.	Use a suitable power supply and power source.

Basic Failure: Voltage Breakdown or "Punch Through." Voltage breakdown is especially critical in surface-barrier types of transistors.

Cause: Safe voltage is exceeded in the nonconducting direction. Allowable values for surface-barrier transistors are on the order of 15 volts from collector to emitter and 0.5 volts from base to emitter. Sometimes 0.1 volts can be excessive.

Possible source of abuse	Suggestion to avoid abuse
Short circuiting series parts, such as the load resistor, with test prods, screwdriver, or soldering iron—thus permitting the voltage on the transistor to rise.	Do not short parts with voltages present. Use very small test prods. Insulate prods to the tips. If a screwdriver is used near active transistor circuits, it should be small and well insulated. Turn off power to transistors before using soldering iron or uninsulated tools. Keep transistor away from high voltage circuits.

Table 2-1.—Continued

Basic Failure: Voltage Breakdown or "Punch Through."—Continued

Possible source of abuse	Suggestion to avoid abuse
Using multimeter on high resistance measuring range (22.5 volts of multimeter AN/PSM-4, for instance, is far too high for surface-barrier transistors).	Avoid use of resistance measuring circuits unless safe. Remove batteries from multimeter or use series and parallel resistors to limit current and voltages to safe values.
Using soldering iron which connects a.c. from line by leakage, or capacitance.	Use 6-volt iron or isolation transformer. Always turn transistor circuits off and, observing safety precautions, connect a common ground before soldering.
Connecting leads from ungrounded test set to transistor.	Ground all cases together using short ground connections. Use all safety precautions necessary.
Using transformerless a-c sets, or test sets.	Not recommended. However, if necessary to use them, connect an electrostatically shielded isolation transformer (1:1 ratio) in the power line of the transformerless set for safety, and use common ground. Check voltages before connecting test leads between equipments to assure safe values.
Using equipment with faulty power supply.	Repair power supply.
Accidentally connecting other voltages to transistor.	Check for test lead voltage that might damage transistor, and if evident, eliminate it before connecting. Ground and short probes and test leads to discharge any test set capacitors before connecting, when applicable.

QUIZ

1. When indium is combined with pure germanium, the resulting structure produces a semiconductor called a/an
   a. acceptor
   b. donor
   c. p-n-p transistor
   d. n-p-n transistor

2. The forward bias of a transistor operating class A is increased. The collector current
   a. increases
   b. decreases
   c. remains the same
   d. is cut off

3. In transistors a major factor limiting frequency response is the transit time. Another undesirable effect caused by transit time is
   a. thermal agitation
   b. shunt capacitance
   c. phase shift
   d. hill potential

4. When using transistors at higher frequencies, the frequency response may be improved by using the
   a. point-contact transistor
   b. n-p-n junction
   c. heat sink
   d. n-p-i-n junction

5. Noise factors of transistors compare unfavorably with vacuum tubes. The noise factors of p-n-p transistors reduce as
   a. frequency decreases
   b. frequency increases
   c. collector voltage is increased
   d. reverse bias is decreased

6. In transistors the current gain of a single stage may be actually less than unity, but there can be considerable gain in power. This is true in a common base transistor circuit because the collector has a high
   a. voltage potential
   b. heat coefficient
   c. impedance load
   d. electron capacity

7. In the transistor circuit shown in figure 2-16, the input voltage swings positive. This results in
   a. decreased emitter current
   b. decreased heat dissipation
   c. positive output voltage
   d. decreased collector voltage

8. In figure 2-20, the 5K resistor opens. The result would most likely be
   a. transistor destruction
   b. oscillator cutoff
   c. greater gain
   d. greater distortion at low frequencies

9. Refer to figure 2-21. With potentiometer R_1 adjusted for 5 volts r.m.s., an 8-volt peak signal is applied through C_1. The NO-GO light is lighted. This indication could be caused by
   a. V_1 being ionized
   b. C_4 being open
   c. RL_1 stuck in the energized position
   d. normal operation

10. In order to have a transistor oscillator without an external feedback circuit, it would be necessary to incorporate a
    a. point-contact transistor
    b. unity gain transistor
    c. second transistor for amplification
    d. high alpha junction transistor

11. Transistors will probably be used more extensively in the future because they
    a. require little skill and understanding to service
    b. require no field maintenance
    c. have a long life expectancy
    d. are small and have excellent high frequency response

12. With reverse bias applied to p-n junction
    a. holes in the p-type material are attracted to the junction
    b. electrons in the n-type material are attracted to the junction
    c. the region close to the junction attracts all the electrons and holes
    d. the region close to the junction has all its electrons and holes removed

13. In a transistor the collector corresponds to what element in a vacuum tube?
    a. Plate
    b. Cathode
    c. Control grid
    d. Heater

14. The n-type point-contact transistor is similar in operation to the
    a. germanium diode
    b. p-n-p junction transistor
    c. n-p-n junction transistor
    d. silicon diode

15. In a junction type transistor, "alpha" is always less than unity. This indicates the
    a. collector current is greater than emitter current
    b. emitter current is greater than collector current
    c. base current is greater than collector current
    d. base current is greater than emitter current

16. The common-base transistor circuit is analogous to the
    a. cathode-follower vacuum-tube circuit
    b. grounded-cathode vacuum-tube circuit
    c. grounded-grid vacuum-tube circuit
    d. common-heater vacuum-tube circuit

17. Refer to figure 2-20 (grounded-emitter to grounded-emitter cascaded transistor amplifier). The feedback circuit
    a. increases the overall gain of the circuit
    b. feeds a portion of the output back to the collector
    c. produces partial cancellation required for regenerative feedback
    d. improves the frequency response of the circuit

18. Alpha cutoff is defined as that frequency where the value of alpha has decreased to
    a. 63.7 percent of its normal rated value
    b. 70.7 percent of its normal rated value
    c. 50 percent of its normal rated value
    d. 90 percent of its normal rated value

19. A main characteristic of the common-collector transistor amplifier is
    a. low output impedance; high input impedance
    b. high output impedance; low input impedance
    c. a voltage gain greater than unity
    d. a phase reversal between input and output

20. A heat sink is a device which
    a. increases the maximum temperature rating for a transistor
    b. maintains a constant operating temperature for a transistor
    c. increases the power handling capabilities of a transistor
    d. checks transistor operation throughout its specified temperature range

21. Transistor alpha is defined as the ratio of the change in__________ current to the corresponding change in _________current when the_________ voltage is held constant.
    a. base; collector; collector
    b. base; emitter; emitter
    c. collector; emitter; collector
    d. collector; base; collector

22. When soldering near a transistor, a_____ soldering iron should be used.
    a. small very hot
    b. large very hot
    c. small
    d. large

23. Before applying any test signal or a multimeter to a transistor circuit, the technician should first check the allowable _______ , _______ , and _________ ratings of each transistor.
    a. power, impedance, resistance
    b. voltage, power, resistance
    c. current, voltage, power
    d. current, voltage, resistance

24. The surface-barrier transistor is very sensitive to
    a. current change
    b. overload
    c. high resistance
    d. voltage change

25. A factor which requires special care is that transistor circuits generally contain bypass and coupling_________with much lower voltage ratings than conventional test equipment.
    a. capacitors
    b. resistors
    c. inductors
    d. transformers

CHAPTER 3

MAGNETIC AMPLIFIERS AND THEIR APPLICATIONS TO MISSILES

The magnetic amplifier, a rising competitor of the vacuum tube in power and control applications, is rapidly becoming an important element in naval electronics. Amplifiers of this type have many features which are desirable in military equipment. They provide large amounts of power or voltage gain. They are rugged and reliable, require no cathode heating and no high d-c operating potentials, and are relatively simple in construction and operation.

Until comparatively recent times, magnetic control has had little application in naval electronic equipment since existing units were slow in response and were of excessive size and weight. But with the development of new and improved magnetic materials, there has been a parallel development of magnetic circuits for tubeless amplification; and many of these units are now employed in guided missiles and in associated missile test equipment.

Magnetic amplifiers are devices which control the degree of magnetization in the core of a coil in order to control the current and voltage at the load or output. One of the oldest forms of magnetic amplifiers, the saturable reactor, contains at least two coils wound on a common core made of magnetic material. A d-c control voltage is applied to one of the coils; and the resulting current serves to modify the reactance of the second winding by causing magnetic saturation of the common core. The second coil is a series element in the a-c load circuit so that current variations take place in the load in accordance with those made in the control voltage. In more complex magnetic amplifiers, the input, or control signal, may be either d-c or a properly phased a-c voltage.

In addition to saturable reactors, there are numerous types of magnetic units in use, including voltage regulators, low- and high-frequency amplifiers, and servomotor controllers. It is the purpose of this discussion to present the operating principles of these devices and to give representative examples of magnetic circuits employed in missile equipment. Before beginning the chapter, the trainee is requested to study carefully *Basic Electricity*, NavPers 10086, chapter 7, which provides a coverage of magnetic fundamentals and thereby serves as an introduction to the material contained in the following sections.

Basic Principles of Operation

Basically, a magnetic amplifier consists of a controlled variable inductance in series with an a-c power supply and a load resistor. The control action involves changes in the magnetic permeability of the inductance coil with resulting changes in inductance, inductive reactance, and impedance of the load circuit. As a result, changes are made in the current flowing in the load and the voltage developed at the output.

As explained in *Basic Electricity*, inductance (often called electrical inertia) is the primary electrical property of any coil. The inductance value of a particular coil is determined by its physical characteristics; and in general, it can be increased in an air-core winding, for example, by inserting a core made of magnetic material. The reason for this effect can be seen by considering the factors that influence inductance as expressed in the following formula:

$$L = \frac{1.256\ N^2 A \mu 10^{-8}}{\ell}$$

where

L = inductance in henries
N = number of turns
A = area of the core in square centimeters
μ = permeability of the core material
ℓ = length of the core in centimeters

The permeability of a substance is a measure of the ease with which it conducts magnetic lines of force when compared with some convenient reference material such as air. When air is taken as the standard, its permeability is one (1). On this basis, the permeability values of ferromagnetic materials, such as iron and steel, range from approximately 60 to 6,000.

From the inductance equation, it can be seen that the inductance of an air-core winding can be increased enormously by inserting a core made of ferromagnetic material. Thus, if an iron-alloy core with a permeability of 1,000 is inserted, the inductance becomes 1,000 times greater than the former value with an air core. The effect of this change when the coil is used as a series current limiting element can be shown by means of a diagram.

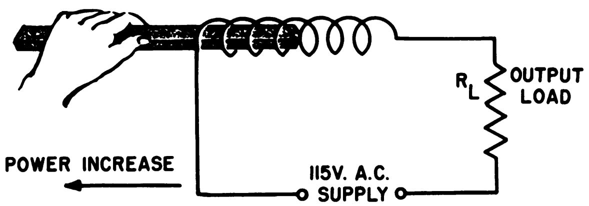


Figure 3-1.—Varying inductance manually.

A very simple circuit is shown in figure 3-1 to illustrate the fundamental control process. The iron core is moved in and out of the winding to alternately increase and decrease the effective permeability. This varies the inductance and hence the inductive reactance in series with the load resistor. When the core is completely within the winding, the inductive reactance is maximum and the voltage drop across the coil is a large fraction of the applied voltage. As a result, the load voltage is low and the current flow is minimum.

Removing the core from the coil (fig. 3-1) lowers the inductance, decreases the inductive reactance, and permits the current to rise and the voltage drop across the load resistor to increase proportionately. By means of this simple arrangement, a comparatively small amount of energy is sufficient to control the output of a source with a possible rating of several horsepower; and for this reason, the circuit functions as a magnetic amplifier.

In more practical forms of magnetic control, large a-c sources are controlled by a method which gives much the same result as the circuit shown in figure 3-1. In these circuits, the series winding has a fixed magnetic core, the permeability of which is varied by saturating or unsaturating the material with a relatively small control current.

When the control current is increased sufficiently to saturate the core, the inductance is lowered, and the reactance is then about the same as that of an air-core winding under similar conditions. With a reduction in control current, the core becomes unsaturated, the reactance increases, and the output current and voltage decrease. The principal features of this process can be made clear by reviewing some of the basic magnetic concepts and by considering the magnetization curve of a typical core material.

It will be recalled that when current flows in a coil, there is a resulting magnetomotive force, which in the magnetic circuit is comparable to applied voltage in the electric circuit. The strength of the magnetomotive force is determined by the ampere turns, the product of the current flowing in the coil and the number of turns.

The magnetomotive force produces magnetic flux consisting of closed lines of force that are comparable to current in the electric circuit. The quantity of flux, or the total number of lines, varies directly with the amount of magnetomotive force but inversely with the reluctance of the path comprising the magnetic circuit. Magnetic reluctance, the quantity analogous to electrical resistance, is a property of the material in which the flux lines are established; and in the case of the electromagnet, or coil, the reluctance value is determined principally by the nature of the core.

The reluctance of an air core remains constant regardless of the applied magnetomotive force and the quantity of flux. However, when a ferromagnetic substance is used as a core material, the reluctance is no longer constant. Instead, as the magnetizing current begins to flow, the reluctance is low and the resulting flux is very high compared with the flux existing in an air-core coil under similar conditions. As the magnetizing current is increased,

the reluctance increases and the rate-of-flux-increase falls off.

When the current reaches a certain value, depending on the core material, the reluctance increases very rapidly, its value approaching that of air. In this condition, further increase of the magnetizing current produces comparatively small increase in total flux and the core is said to be saturated.

The condition of saturation and the resulting effects on permeability and inductance can be illustrated by the curve shown in figure 3-2. In this graph, the flux density (B) in a typical material is plotted against the magnetizing force (H), which is proportional to applied ampere turns. The ratio of the two values, or B/H, is equal to the permeability of the material. And from the shape of the curve, it is seen that permeability is not constant but has different values for different amounts of magnetizing force.

From point a to point b, (fig. 3-2), the curve rises steeply in what is substantially a straight line. In this region, the permeability is high and the coil has a large inductance value. From point b to point d, a small change in H produces a much smaller change in flux density than on the linear part of the curve. Here, the permeability is lower and the inductance is correspondingly smaller. From point d to point e and beyond, the curve is almost flat, indicating a very small increase in B as H is increased. In the latter condition, the core is saturated and the inductance is minimum.

Since the basic control action of the magnetic amplifier depends upon changes in inductance, the region between points b and d (fig. 3-2) represents the ideal operating range. If the action is such that control signals swing the magnetization about point c, comparatively small changes in input result in large variations in output-circuit impedance. In most modern applications of magnetic amplifiers, the saturation method is used since it simplifies the operation, permits faster response, and eliminates moving parts.

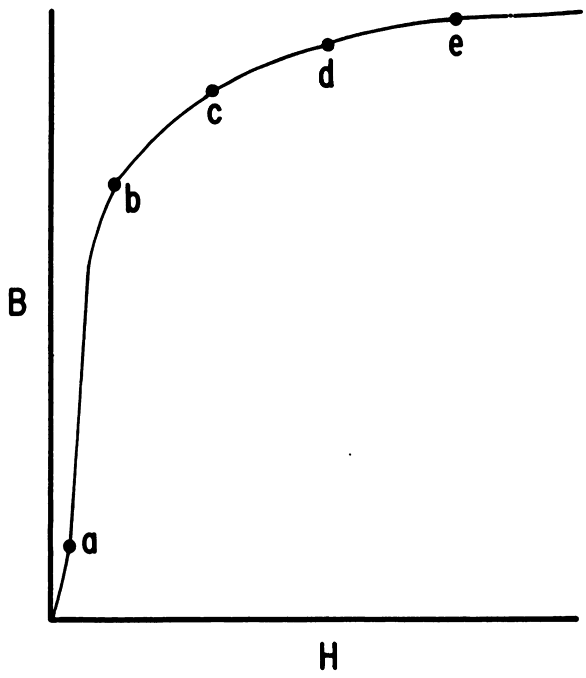


Figure 3-2.—Magnetization curve.

Fundamentals of Magnetic-Amplifier Circuits

The various forms of magnetic amplifiers used in practical applications have certain circuit elements in common, including d-c or a-c control windings, dry-disk rectifiers; special forms of magnetic cores; biasing coils; and feedback circuits. Among the processes of importance are hysteresis effects and the actions determining speed of response of the amplifier.

In this section, these components and processes are introduced by considering first a basic circuit to illustrate the fundamental method of control. This circuit is then developed into more complex form by addition of components which increase or improve the response.

THE BASIC CIRCUIT

The basic arrangement of components for controlling a-c load power by means of a control coil is illustrated in figure 3-3. Two windings are required, both of which are wrapped on a common core. The control winding shown on the left, is supplied from a d-c source, and the control current is adjusted by a potentiometer. It is the purpose of the control current to establish a unidirectional flux in the core with an intensity determined by the d-c ampere turns of the control circuit. The second coil, the load winding, is connected in series with an a-c power source and the load resistance, which in this case is a lamp.

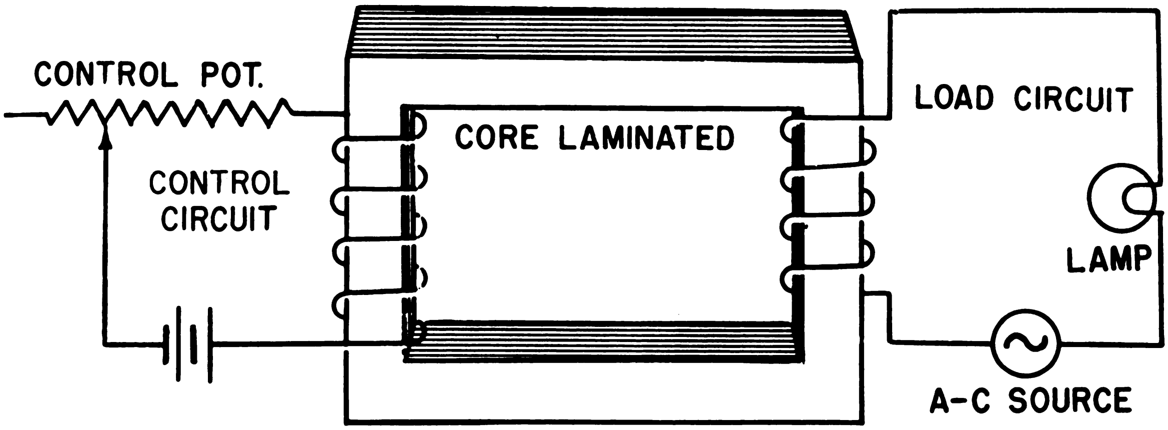


Figure 3-3.—A simple magnetic amplifier.

With the circuit (fig. 3-3) operating on the knee of the magnetization curve, a small increase in control current lowers the inductance of the load winding. This occurs because the degree of magnetization is shifted to a point on the curve where the slope approaches the horizontal, and the permeability of the core material is thereby decreased. As a result, the inductive reactance of the load winding is lowered; the total load-circuit impedance falls off; and the load current rises, causing the power developed in the load to increase.

If control current increases enough to saturate the core completely, the load winding reactance drops nearly to zero, leaving the resistances of the winding and of the load as the principal current limiting elements. In this condition, maximum supply voltage is applied to the load, and the lamp then glows at maximum brightness.

On the other hand, decreasing the control current causes an increase in the reactance of the load winding since the operating point is moved toward the steep part of the curve, thereby increasing the permeability. With the coil at maximum inductance, there is a corresponding minimum value of load current and consequently minimum load power. Thus, for a small change in control power, the magnetic action produces a large change in load power, so that the device functions as an amplifier.

Although the explanation just given illustrates the basic method of controlling core permeability, the arrangement shown in figure 3-3 is seldom used because it is a very inefficient magnetic amplifier. Transformer action takes place so that energy is coupled from one winding to another. The alternating flux resulting from secondary, or load current, induces voltage into the control winding. If the latter coil has a large number of turns, the induced voltage may become excessive and may even break down the insulation. Even if the coupled voltage is small, the control circuit acts as a low-resistance winding and dissipates a considerable amount of energy that would normally be applied to the output.

It is possible to reduce the losses resulting from unwanted coupling by inserting an isolating impedance in the form of an inductance placed in series with the control winding; or losses may be minimized by the use of a three-legged core. The latter method is described in the following pages.

Three-Legged Magnetic Cores

A more satisfactory circuit arrangement results when the basic amplifier is modified as shown in figure 3-4. This device, called a saturable reactor, is often employed for controlling large amounts of alternating current. It contains a three-legged core with an a-c winding on each outer leg and a d-c control winding on the center leg. The chief advantage of this core structure is that alternating flux components produced by currents in the load windings are balanced out in the center leg and do not affect the control circuit. However, this desirable condition exists only if the two a-c coils have equal numbers of turns and are wound so that the flux lines oppose, as indicated by the dotted line in the drawing.

While alternating flux does not pass effectively through the center leg (fig. 3-4), the two

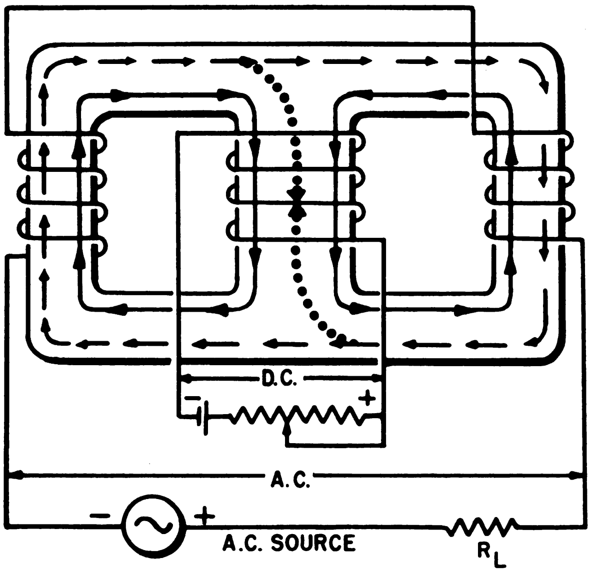


Figure 3-4.—Magnetic amplifier with three-legged core.

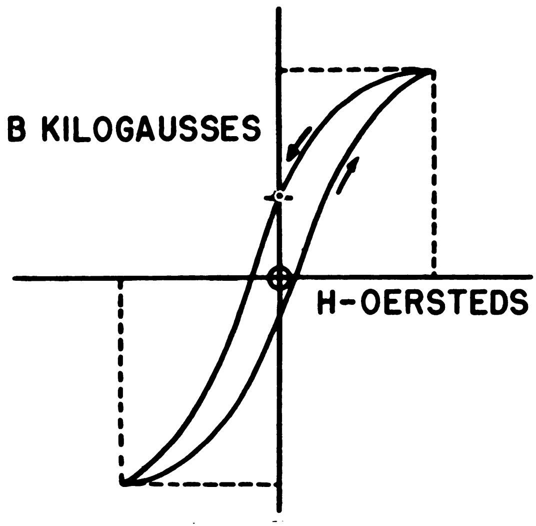


Figure 3-5.—Hysteresis curve.

components add along the path through the outer legs of the core as indicated by the broken lines. The drawing also shows that the control current produces a magnetic flux (represented by solid lines) that magnetizes the entire core of each load winding. Thus, while the d-c coil can influence the operation of the load circuit, there is no coupling of energy by transformer action from the load circuit to the control winding.

During normal operation, variations of the control current result in corresponding changes in core permeability; and this, in turn, readjusts the inductive reactance in series with the load. Hence, as far as the control process is concerned, the operation of the saturable reactor is similar to that of the basic magnetic amplifier.

Magnetic Amplifiers with Half-Wave Rectifiers

The operation of the simple amplifier (fig. 3-3) is inefficient; and it has an additional disadvantage in the relatively large amounts of control current are required. This results because the control ampere turns must overcome the effects of the comparatively large a-c load current, which establishes sinusoidally varying magnetic flux in the core. The intensity and direction of the magnetic field produced by load current when no control current is flowing can be shown better by a hystersis curve, as in figure 3-5.

The interpretation of the hysteresis curve for typical core materials is given in detail in *Basic Electricity*, NavPers 10086, chapter 7. It is sufficient here to note that the magnetizing force (expressed in oersteds) varies along the horizontal axis of the graph in accordance with the a-c current applied by the power source. As a result, the magnetic flux density (in gausses) has values both above and below the zero level (fig. 3-5), indicating a regular change in direction of the flux lines. Thus, in the operation of the magnetic amplifier, the flux created by the load current impedes the control flux during one half-cycle and aids it during the other.

In order to produce sufficient flux to balance out the oscillating flux of the load currents, the ampere turns provided by the control winding must equal the ampere turns of the load windings. In addition, sufficient extra control magnetizing force is needed to set the operating point at the desired place on the magnetization curve. The combination of these two demands results in a very ineffective amplifier since the control-circuit ampere turns must exceed the ampere turns of the load circuit. The solution of this difficulty is in the use of rectifier units, which eliminate the unwanted currents and permit self-saturating operation of the amplifier.

A more efficient magnetic amplifier is shown in figure 3-6. A half-wave rectifier (usually of the dry-disk type), inserted in the load circuit, permits current to flow in one

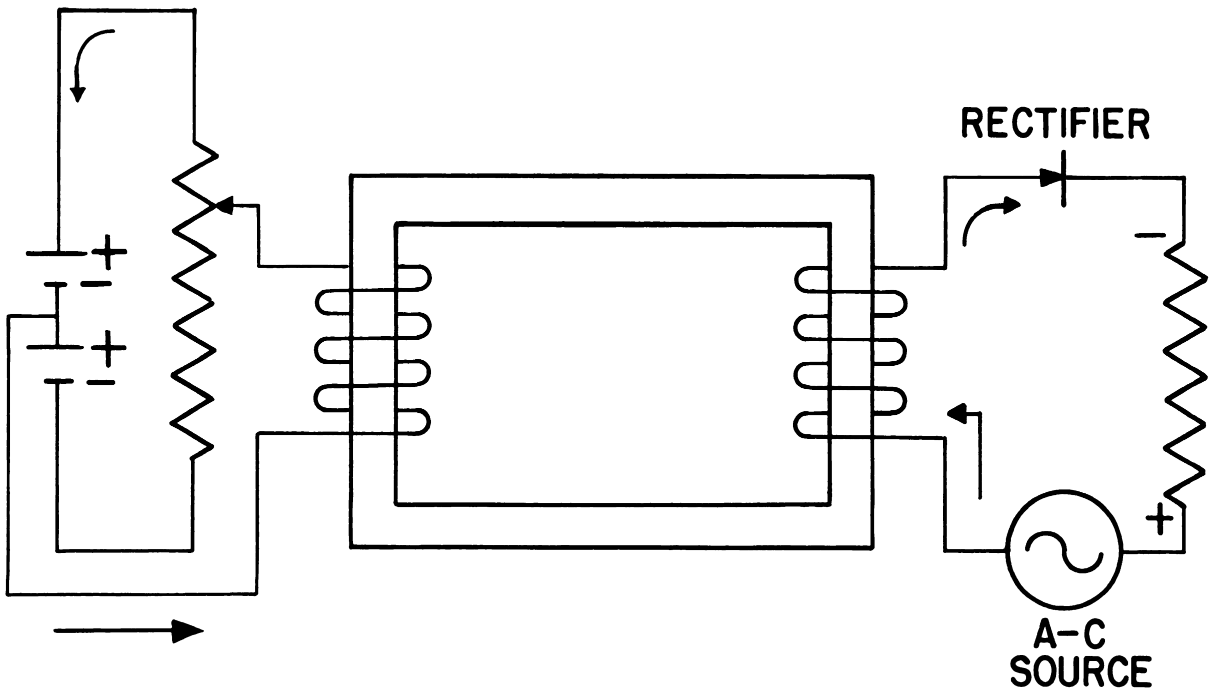


Figure 3-6.—Magnetic amplifier with half-wave rectifier.

direction only. Because of the unidirectional load current, one-half of the formerly oscillating flux is eliminated; and the remaining field may either assist or oppose the control flux, depending on the position of the arm of the control potentiometer. The arrows in the drawing indicate the direction of electron flow. In the case illustrated, it can be seen by applying the left-hand rule for determining the direction of the magnetic fields, that the load flux assists the control flux in saturating the core. By moving the arm of the control potentiometer toward the negative end, the fields would then be made to oppose. In either case, however, a more effective amplifier is provided since less control power is required for a given amount of output power.

The action of the circuit with the rectifier limiting the load current to unidirectional flow can be interpreted as a form of feedback. Since the entire feedback effect takes place within the magnetic circuit comprised by the core and is accomplished without the use of additional coils or control elements, it is classified as internal feedback. The use of additional circuit elements to provide external feedback is discussed in detail in a subsequent part of the chapter. Consider first, the process by which the load circuit is made to assist the control action in the self-saturating magnetic amplifier.

Self-Saturating Magnetic Amplifier

The operation of the self-saturating amplifier can be understood by use of a magnetization curve in which the hysteresis effect is eliminated as in figure 3-7. Point 1 on the curve indicates the condition of the control flux when the potentiometer (fig. 3-6) is set to apply a negative control voltage. Under this condition, the control flux is in opposition to the flux resulting from load current. If the amplitude of the latter is such that the total core flux varies along the curve from point 1 to point 4, the impedance of the secondary remains large; and the voltage drop across the load resistor is very low. The relation of the applied voltage to the load voltage is shown in the lower drawing of figure 3-7 (B).

When the potentiometer arm is moved toward the positive end, the control current flows in the same direction as before but with less amplitude. The rectified load current then varies the core flux between points 2 and 5 on the magnetization curve (fig. 3-7). Under this condition, partial saturation of the core results, and the output waveform resulting is shown in drawing 2 of figure 3-7 (B).

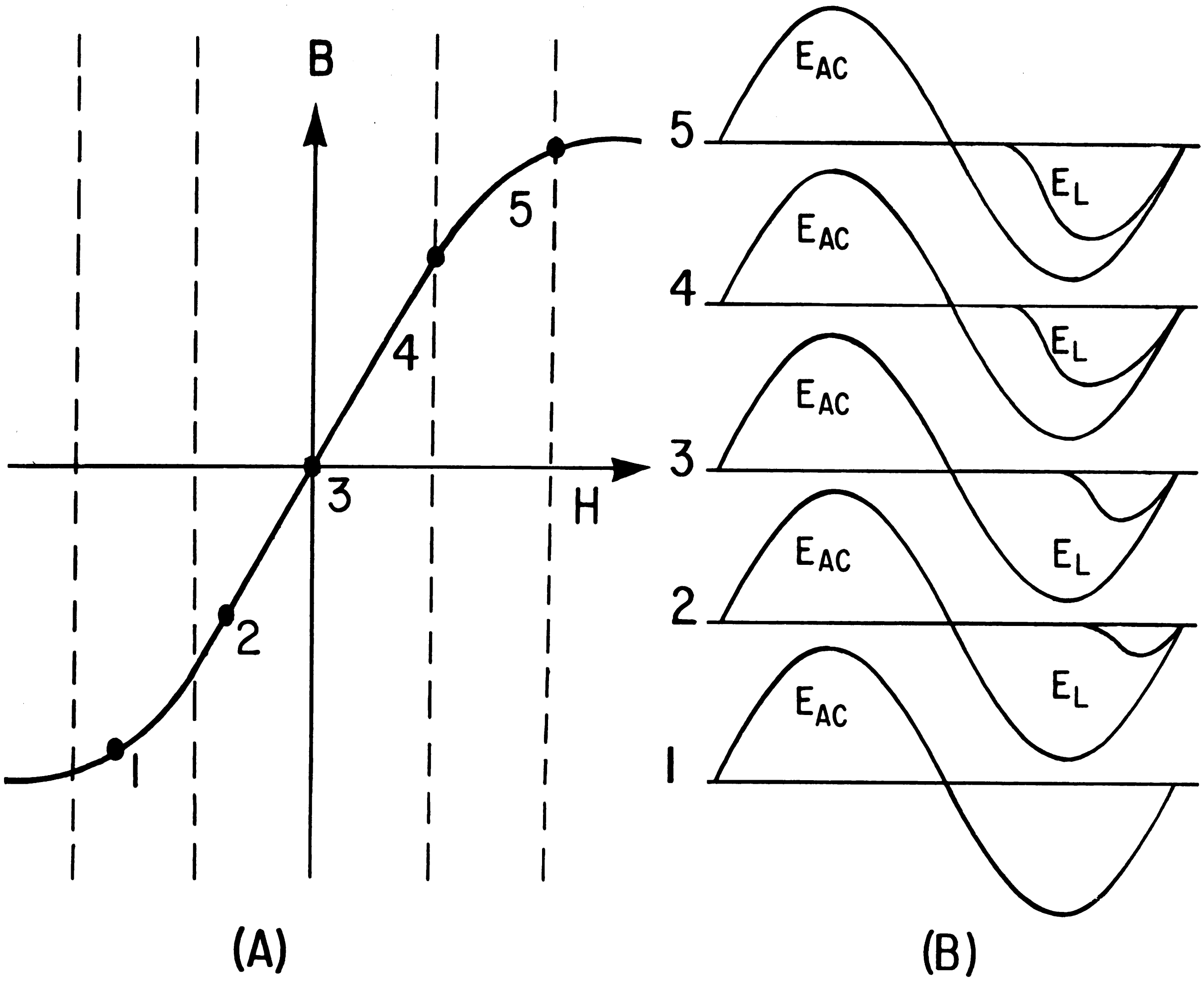


Figure 3-7.—Operation of self-saturating magnetic amplifier.

As the potentiometer is moved nearer the positive end, placing the operating point to position 3, the control current is then zero. The resulting waveform at the output is that shown in drawing 3 of figure 3-7 (B). At position 4, the control voltage and current are reversed with respect to the original direction, producing a corresponding reversal of control flux. In this condition, the control flux assists the load flux and saturation is reached at an earlier instant in the a-c cycle. The resulting output is shown in drawing 4; while drawing 5 of the same figure shows the output current when the control voltage is made even more positive.

Effects of Hysteresis on Operation

In the preceding discussion of the basic magnetic amplifier, the magnetic characteristics of the core material are largely neglected, and emphasis is placed on the function of the fundamental components. In order to understand fully the operation of self-saturating amplifiers, it is necessary to consider the shape of the hysteresis loop and its significance in circuit operation.

The B-H curve of a typical magnetic material is shown in (A) of figure 3-8. Assume that this material is used as the core of a magnetic amplifier of the type illustrated in figure 3-6. The amplifier has two distinct periods of operation: the interval during which the rectifier conducts is called the operating period; while the nonconducting half-cycle of applied voltage is called the control period. The solid part of the loop in (A) indicates the variation of flux within the core when the control voltage is set at zero so that no control current flows. During the operating

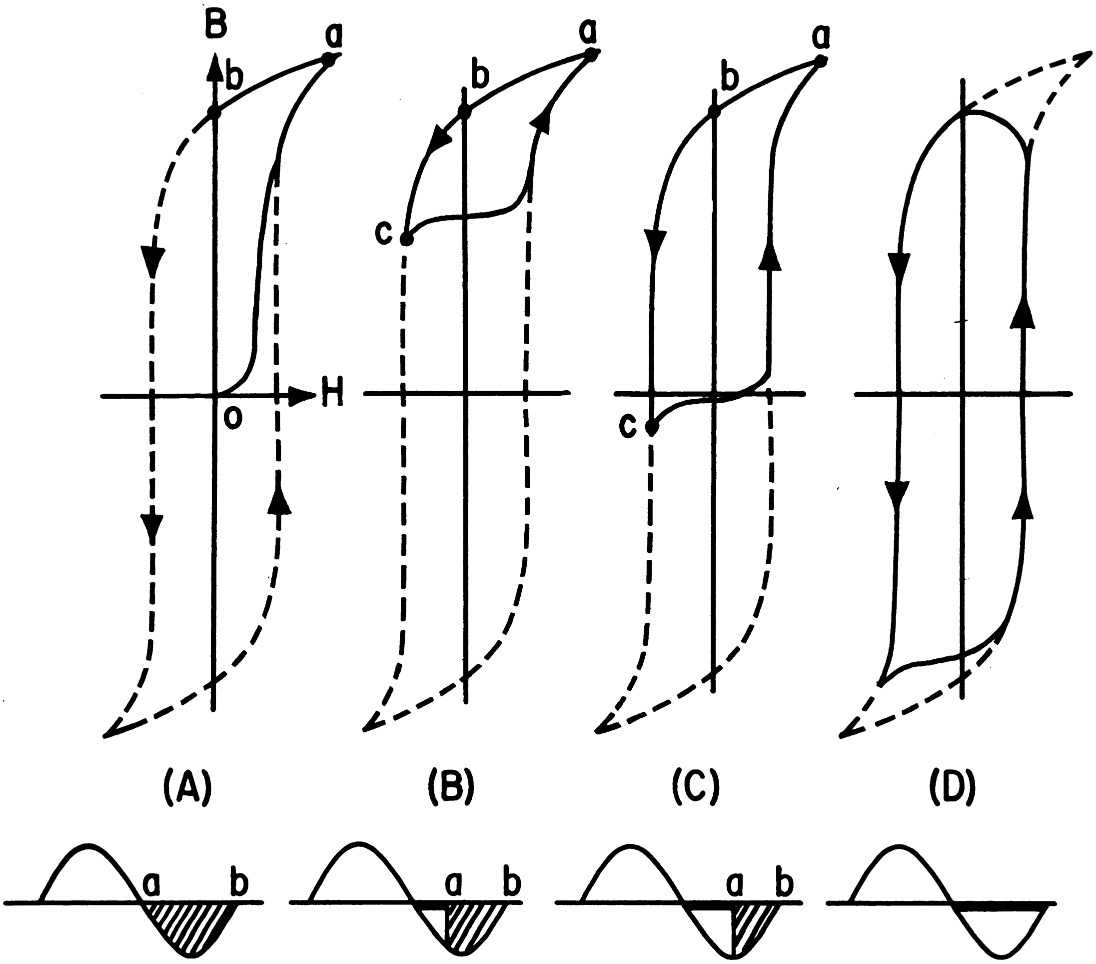


Figure 3-8.—Operation of magnetic amplifier showing effects of hysteresis.

period, the load current, which is assumed to be of sufficient amplitude to saturate the core, swings the flux from point o on the curve to point a, the saturation value.

At the end of the first operating period, the degree of magnetization returns, not to the original starting point, but to point b (fig. 3-8) because of retentivity of the core. (This value on the graph is called the remanence point. It indicates the amount of flux left in the material when the magnetizing force is removed and is also a measure of the usefulness of the material to serve as a permanent magnet.) The part of the loop shown in broken lines in (A) of figure 3-8 represents the further change in magnetization that would occur if the magnetizing current were permitted to reverse in direction to complete the normal hysteresis graph.

The core remains magnetized at the remanence point during the control period of the amplifier. During each following half-cycle operating period, the material saturates immediately; and the load current is maximum since no control is exercised. The output waveform for this condition of the control circuit is shown directly under the drawing in (A) of figure 3-8.

Figure 3-8 (B) shows the operation when a small control current is flowing in a direction to cause the control flux to oppose the load-current flux. The initial change in core magnetization is similar to that just described; but when the load current becomes zero, the total flux is placed at the value indicated by point c during the second control period. This process of positioning the residual magnetic flux is called resetting.

Following the resetting action, the next operating period causes the flux to increase; and a small part of the applied half-cycle elapses before saturation is reached with the core at point a. At this point, the rectifier is in maximum conduction and remains so for the rest of the half-cycle. When the control period is resumed, the flux returns to point c, being reset to this value by the action of the control circuit. Thus, the primary function of the control current is to determine the starting value of magnetic flux. The output waveform for this amount of control current is shown directly below (B) of figure 3-8.

Part (C) of figure 3-8 shows the result of increasing the amount of control current. Note that conduction in the output circuit occurs only during the latter half of the operating half-cycle. The result of a large amount of control current is indicated in (D) of the figure. In this case, the reset point is such that the load flux cannot drive the core to complete saturation; and therefore, the output current is substantially zero, as shown in the corresponding waveform.

The method of operation just described is very similar to the action of a thyratron, in which conduction is either maximum or zero, depending on the relationship of the control voltage and the applied plate voltage. The term firing which is often used in referring to thyratron action, is also frequently used interchangeably with the word saturation when describing the similar condition in magnetic amplifiers.

Using Bias for Flux Reset

If the core material has hysteresis characteristics that result in a rectangular-shaped B-H curve, it may be necessary to bias the core to retain control. This is accomplished either by causing a bias current to flow through the control winding or by use of a separate bias coil. With either method, the bias current provides the means for resetting the magnetic flux to the initial operating point during the control period of the amplifier as described in the preceding paragraphs. The use of a separate bias winding for this purpose has the advantage that smaller control current is drawn and loading of the control-voltage source is minimized.

The physical position of the bias winding with respect to the control and load coils in three-legged-core amplifiers is illustrated in

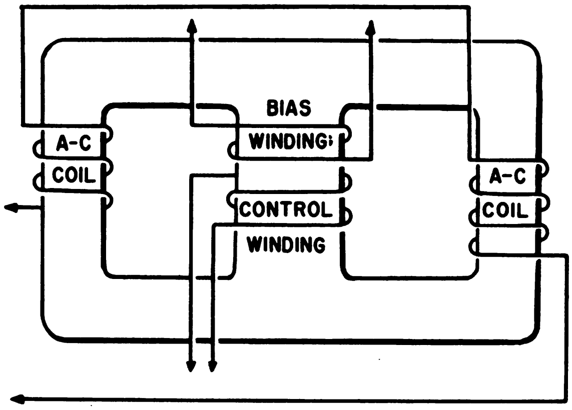


Figure 3-9.—Bias winding.

figure 3-9. The core is usually biased so that with zero control current, the flux resulting from load current saturates the core material midway in the operating period. In this condition, the bias setting corresponds approximately to operating point c in figure 3-8 (C), so that the control current can either advance or delay the point of saturation. Thus, if the polarity of the control voltage is such that the control-current flux adds to the bias flux, saturation is delayed and the amplifier fires later in the operating period. A control signal with opposite polarity results in a control flux that opposes the bias flux and hence advances the firing point.

In most cases, the polarity of the d-c bias supply is selected so that the bias magnetism opposes the load-current flux. The magnitude of the bias is usually such that the core flux is reset to a point on the hysteresis curve between points b and c in figure 3-8 (B). In some applications, the bias polarity is reversed so that it aids the load winding flux and provides quick initial saturation of the core, thereby increasing the amplification of weak input signals. Also, some types of special circuits contain a-c bias systems; however, these have very limited application in missile equipment, and detailed description of them is not justified in the present discussion.

MAGNETIC AMPLIFIERS WITH FULL-WAVE RECTIFICATION

In most applications of magnetic amplifiers, full-wave output is desirable rather than the pulsating, or half-wave, operation previously discussed and illustrated. Full-wave operation in which the load is energized during both

halves of the a-c cycle may be obtained by using a pair of half-wave units.

Typical full-wave circuit arrangements are illustrated in (A) and (B) of figure 3-10. The load current in the amplifier shown in (A) is controlled by means of two control windings connected in series. Each amplifier unit contains a rectifier so that load current flows alternately; and as one unit conducts, the core of the other is reset by the action of the control current. With each rectifier conducting approximately one half-cycle, the output current variations are full wave in nature.

Output current waveforms are shown in (C) and (D) of figure 3-10, which indicate the resultants for two different values of control current. Waveform (C) occurs when the control current biases the core near the point of saturation so that heavy conduction begins early in each half-cycle of applied voltage. If control current is reduced to a lower value, the output resembles the waveform in (D), in which the average value of current over each half-cycle is considerably less than when the operating point is near saturation. As in the operation of the basic circuit, the output power is varied by controlling the flow of load current; but unlike the half-wave amplifier, current is delivered to the load resistance during both half-cycles of applied source voltage.

In operation, the magnetic amplifier shown in (B) of figure 3-10 resembles that illustrated in (A). It differs in circuitry since it contains a single control winding, and also in that two magnetic cores are combined to form what amounts to a three-legged structure. An extremely small air gap separates the two magnetic paths; and the combination may be regarded as two units similar to the circuit illustrated in figure 3-6. The air gap assists in isolating the magnetic flux components resulting from the load coils so that one core remains unsaturated while the other is in saturation. The two load coils conduct alternately

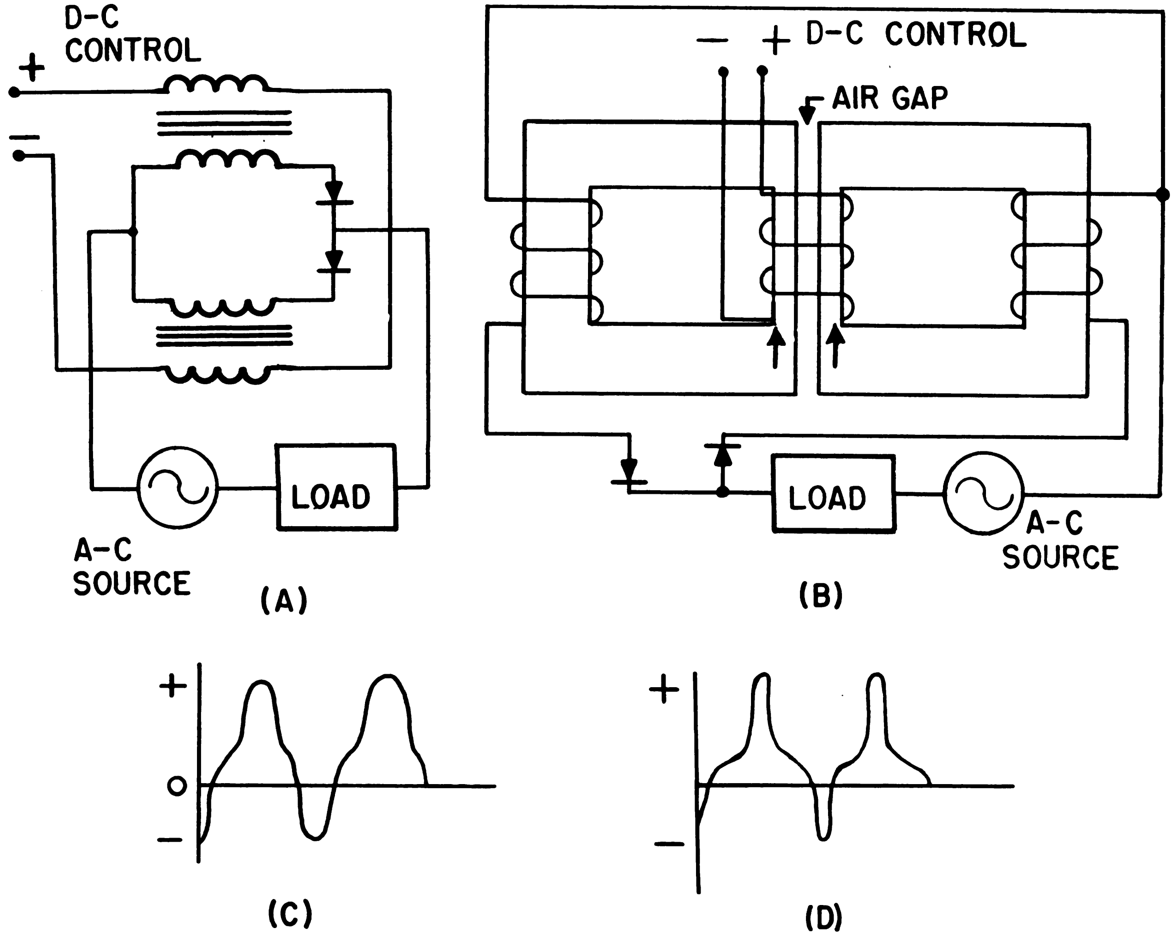


Figure 3-10.—Full-wave magnetic amplifiers and output waveforms.

but in opposite directions through the load resistor; hence the output current waveforms resemble those shown in (C) and (D).

Another variation of core construction involves the use of stacked, circular cores. This is a space saving arrangement which also provides air gaps between the units to eliminate undesirable interaction of the various flux components. Each circular core contains a separate a-c load winding; and the two are stacked coaxially so that the control winding can be put on common to both magnetic cores. The electrical operation is similar to the basic reactor described previously.

FEEDBACK IN MAGNETIC AMPLIFIERS

It is possible to improve many of the operating characteristics of a magnetic amplifier by the use of an external feedback circuit. In many cases, this circuit consists of an additional coil wound on the center leg of the magnetic core. Feedback action occurs when the coil is energized by a portion of the output current and produces a magnetic field that is combined with the control flux established by the input circuit.

Typical feedback circuits are illustrated in figure 3-11. Each amplifier contains dry-disk rectifiers connected in a bridge circuit. In amplifier (A) the rectifier produces a full-wave d-c output both to the load resistor and to the feedback winding. Amplifier (B) has the load in the a-c circuit and the bridge rectifier provides direct current in the feedback winding only.

Feedback in these amplifiers (fig. 3-11) may be either positive or negative, depending on the connection of the feedback winding. If the flux produced by the latter winding aids the control winding flux, the feedback is positive, or regenerative; if it opposes the control flux, it is negative, or degenerative.

The effect of positive feedback is to make the circuit more sensitive to changes in control current so that extremely high values of gain can be achieved. It has the undesirable effect, however, of increasing the response time of the amplifier, and it may also cause instability. The general effect of negative feedback, on the other hand, is to reduce the sensitivity with a corresponding increase in linearity of the magnetization curve and reduction of the time lag.

Load current is plotted against control current in the curves in figure 3-12 to show the effects of feedback on linearity and on the quantity of control current required. The total control current (input plus feedback currents) needed to saturate the core is the same regardless of the sign or the amplitude of the feedback present.

With positive feedback, less control-circuit current is required because of the additive effect of the feedback and control coils. As indicated in figure 3-12, there is a difference between no-feedback saturation current (B) and the control current present with positive feedback (A). This difference is supplied by the output circuit through the feedback winding. When negative feedback is employed, the current drawn by the control circuit must be increased above the no-feedback value to achieve saturation since the feedback flux is in opposition to the control flux. The effect of negative

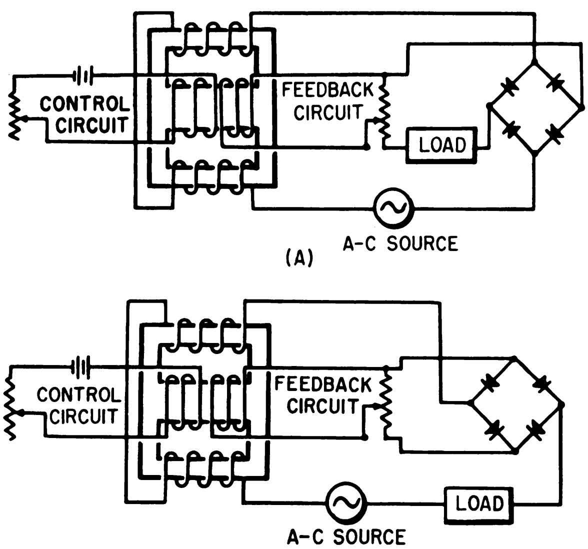


Figure 3-11.—Magnetic amplifiers employing feedback.

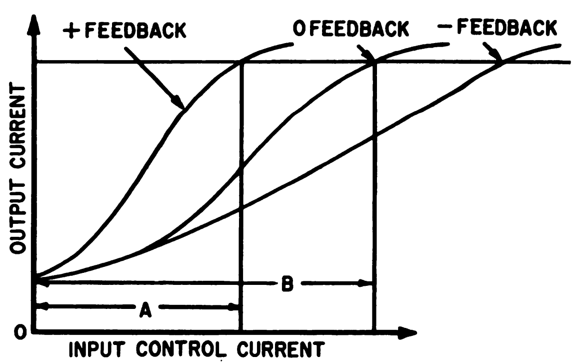


Figure 3-12.—Effects of external feedback.

feedback on linearity of control is indicated by the right-hand curve, which is straight over a much larger range of control current values than the curves for the positive- and no-feedback conditions.

TIME OF RESPONSE

Among the basic characteristics of any magnetic amplifier is a lag or time delay between the introduction of a change in input signal and the development of full response by the load circuit. The cause of the time delay lies in the action of the L-R, or inductance-resistance, circuits of the amplifier. Its value is a measure of the sluggishness of operation; and if the response time is long, the amplifier may be unsuitable for use in equipment such as high-speed missile servo systems.

The time of response of a particular amplifier can be expressed by means of a time constant, which indicates the interval of time in seconds required for the load current to attain a certain percentage of the final value. The greater the time constant, the less rapid is the circuit action. Hence, the time-constant value is a leading factor in determining the upper limit of the frequency range of input signals which can be handled by the amplifier with suitable gain.

In magnetic amplifiers of the type described above, the time constant is determined by the properties of both the control and load circuits. The principal factors are the ratio of the load-circuit and control-circuit resistances, the turns ratio of the control winding to load windings, and the frequency of the power supply in the output circuit. The relationship of these quantities to the time constant is given by the equation:

$$T = \frac{1}{4f_s} \times \frac{N_c^2}{N_L^2} \times \frac{R_L}{R_c}$$

where

T = time in seconds
f_s = source frequency
N_c = number of turns in the control winding
N_L = number of turns in the load windings
R_c = resistance of the input, or control circuit
R_L = resistance of the load circuit

The principal significance of the time constant, T, lies in its relation to the gain of the amplifier with a given input frequency. For adequate amplification, it is necessary that the time constant be short compared with the period of the signal, or the time required for one input cycle. If this is the case, the output current attains the full response for each variation of input voltage. But if T is long relative to the input period, the output variations are low in amplitude because the circuit has insufficient time to reproduce a signal of one polarity before the succeeding change in polarity occurs. Since the period of the input wave varies inversely with frequency, the amplifier should have a rather low time-constant value if the applied signal frequency is fairly high.

It can be seen from the time-constant equation that with a given load resistance and a fixed turns ratio, the response time of the amplifier can be reduced by increasing either the control-circuit resistance or the a-c power supply frequency. In some amplifiers, resistors are inserted in series with the control winding to increase the total resistance of the input circuit. In others, much the same effect is obtained by use of negative feedback. Both these methods have the disadvantage, however, of lowering the effectiveness of the control winding, since the flux resulting from the input signal is reduced.

The inherent time lag of the magnetic amplifier is reduced more conveniently by use of a high-frequency power source. For high-gain operation, the maximum input frequency is usually limited to a low percentage of the a-c source frequency. For medium- and low-gain performance, the input frequency may range up to a value about 50 percent of the source frequency. The factor limiting the a-c source frequency employed in a particular amplifier is the amount of power loss that can be tolerated due to hysteresis effects in the core material. In some cases, sources in the order of several magacycles have been used.

Applications of Magnetic Amplifiers

Magnetic amplifiers are used in many kinds of equipment, both in circuits which contain electron tubes and in those which do not. Among these applications are audio-frequency amplifiers, motor controllers, power-supply regulators, and various types of missile servo

systems. Typical examples of these circuits are described and illustrated in the following pages.

AUDIO AMPLIFIERS

A simplified schematic diagram of a push-pull, a-f magnetic amplifier is shown in figure 3-13. As previously explained, the a-c source should supply a frequency higher than the highest frequency in the audio input signals to obtain a favorable amplification factor. Amplifiers of this type are usually operated as the equivalent of a class AB vacuum-tube amplifier in which output current flows for less than 360 degrees of the input cycle. Class A operation is undesirable because of inefficiency and also because some means would then be required to separate the high-frequency carrier from the modulating voice frequencies.

As indicated in figure 3-13, the circuit employs two reactors, SR_1 and SR_2, each of which contains two control windings—a bias coil and a modulator coil on the center leg of each core. Direct current flowing in the bias coils provides unidirectional flux components, which set the cores at the desired points on the magnetization curve. When no audio modulation is applied from the microphone, approximately equal and opposite currents flow in the two halves of the output transformer; and equal and opposite voltages are developed at points a and b with respect to point c, the center tap. In this condition, no output signal is applied to the speaker.

The application of audio modulation produces an alternating flux in each reactor core that aids the unidirectional bias flux during one half-cycle and opposes it during the other. With aiding flux, the reactor saturates and goes into heavy conduction. At the same time, the other reactor contains modulation flux that opposes the bias and sets the operating point farther from saturation. In this condition, the second reactor has no appreciable effect on the output.

Consider the case in which the flux components are as indicated by the arrows in figure 3-13, causing reactor SR_2 to conduct. Both load coils on the outer legs carry current simultaneously so that two in-phase currents flow, one of which is conducted to point a and the other to point b. However, because of the direction of winding, the degree of saturation differs in the two coils; and the current in one leg is heavier than the current in the other.

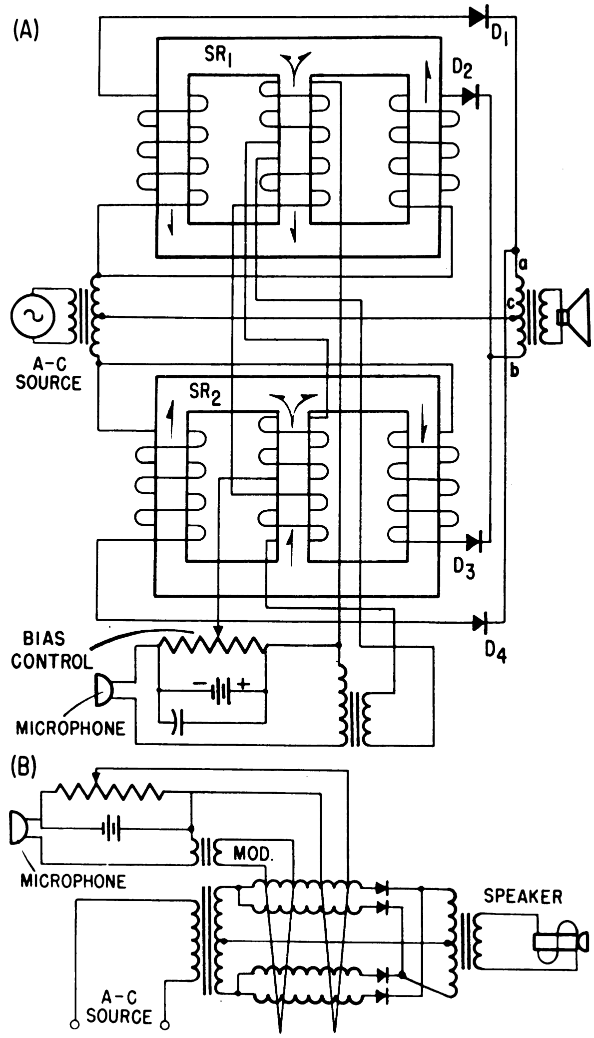


Figure 3-13.—Push-pull audio-frequency magnetic.

The current difference results in an increased voltage drop across one half of the output transformer and a decreased voltage drop across the other half. Then, since the voltages across the primary are no longer equal and canceling, an output voltage is developed in the secondary which varies in amplitude with the applied modulation signal.

On the second half of the input modulation cycle, the situation reverses; and reactor SR_2, which was in saturation, then has a modulation flux that opposes the bias flux and takes the reactor out of heavy conduction. The second reactor, SR_1, then operates in the same manner as the first did during the first half-cycle since the modulation flux within it then aids the bias flux.

Thus, the two reactors operate in push-pull; and for a sinusoidal input, the output wave across the secondary of the transformer closely resembles a sine wave. Note that in this circuit, the modulation flux must aid the bias in order to permit the reactor to go into saturation.

The voltage and current present at various points in the push-pull circuit are illustrated in figure 3-14. Part (A) shows the a-c source voltage, a high-frequency wave of constant peak amplitude which is fed to the a-c windings of the reactors.

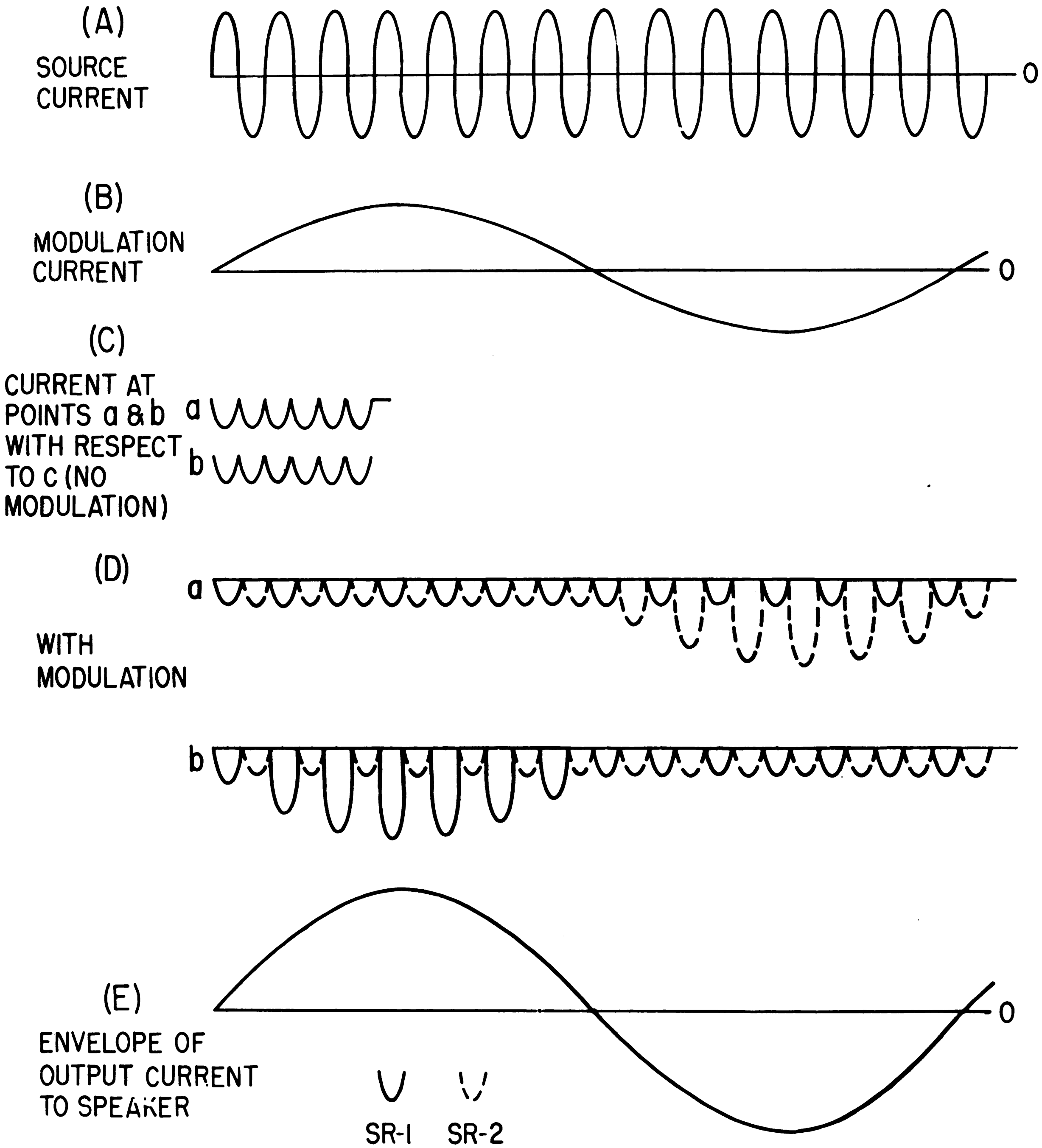


Figure 3-14.—Waveforms in push-pull magnetic amplifier.

One cycle of audio modulation current is indicated in figure 3-14 (B); and (C) illustrates the currents flowing from points a and b toward point c when no modulation is applied. Under this condition, the reactors are biased so that both conduct equally in each leg; and because of the dry-disk rectifiers, these currents are unidirectional pulses occurring during alternate half-cycles in each leg.

Part (D) of figure 3-14 shows the current waveforms in the two halves of the primary when modulation is applied. Note that one of the reactors conducts heavily in one leg and lightly in the other during one-half of the modulation cycle, and the second reactor responds in a similar manner in the remaining half-cycle. The current delivered to the speaker is shown in (E) of the drawing.

APPLICATIONS IN SERVOMECHANISMS

One of the most frequent uses of magnetic amplifiers in missile equipment is in servomechanism systems. In these applications, the magnetic units have the desirable features of long life, need for minimum servicing, and the ability to handle large amounts of power for energizing electric motors and other load actuating devices.

Motor Controller

Figure 3-15 shows a magnetic servo amplifier which controls the voltages for both

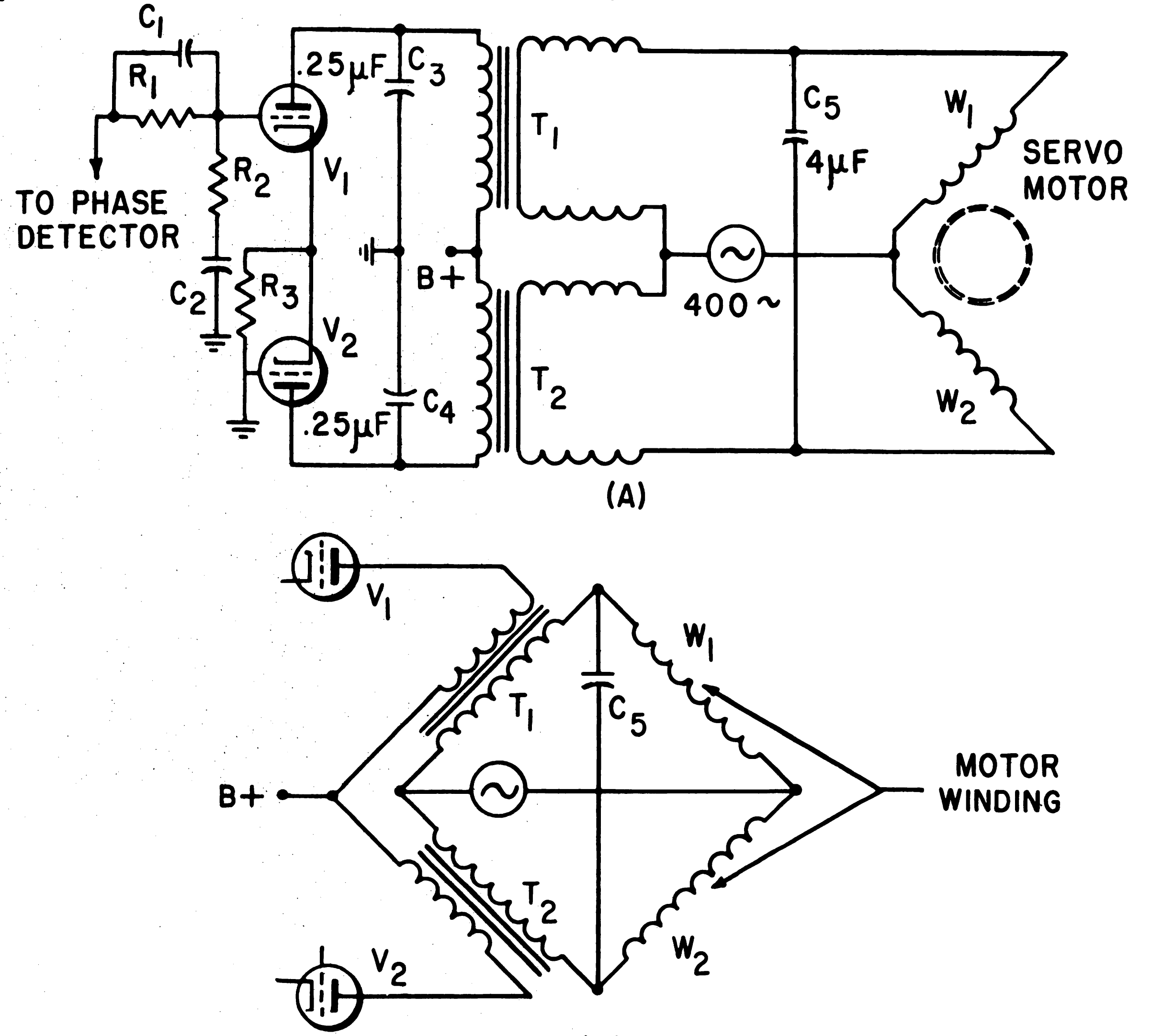


Figure 3-15.—Magnetic amplifier used to control a two-phase induction motor.

phases of a two-phase electric motor. The input signals for the magnetic amplifier are produced from a phase detector. These drive V_1 and V_2, which are connected as a cathode coupled paraphase amplifier working into two saturable reactors.

With zero input, both tubes (fig. 3-15) draw equal amounts of current in the plate circuits. These currents are insufficient to saturate the cores of the reactors; and therefore the impedance of each load winding is very high and the resulting load currents are small. In this condition the circuit is a balanced bridge as indicated in part (B) of figure 3-15; and the motor does not rotate since in-phase voltages are applied to the motor windings.

When an input control signal is supplied from the phase detector, one of the tubes (depending upon the phase and amplitude of the signal) goes into heavier conduction than the other. Under full conduction conditions, the reactor in one plate circuit then appears as a low impedance and the other reactor approaches the open-circuit condition. The bridge is then unbalanced; and capacitor C_5 is effectively connected in series with one of the motor windings, where it causes a phase shift and the motor begins to rotate.

Assume, for example, that V_1 (fig. 3-15) goes into heavy conduction and that V_2 is at effective cutoff. The secondary inductance of T_1 is then practically zero and motor winding W_1 is connected across the a-c source. The inductance of secondary T_2 is high so that the winding resembles an open circuit; and motor winding W_2 is then connected across the a-c source through the phasing capacitor. The phase relations of the resulting currents cause the motor to rotate in a direction determined by which winding is connected in series with the capacitor so that the motor then turns in the opposite direction.

Wing-Servo Valve Controller

One of the principal applications of the magnetic amplifier in missile equipment is in wing-servo systems. In these, the magnetic units are used to operate hydraulic or pneumatic valves that regulate fluid flow to the wing actuators. A typical example is illustrated in figure 3-16, which shows a magnetic amplifier designed to control the position of an armature. The latter is mechanically coupled to the valve in the wing positioning equipment.

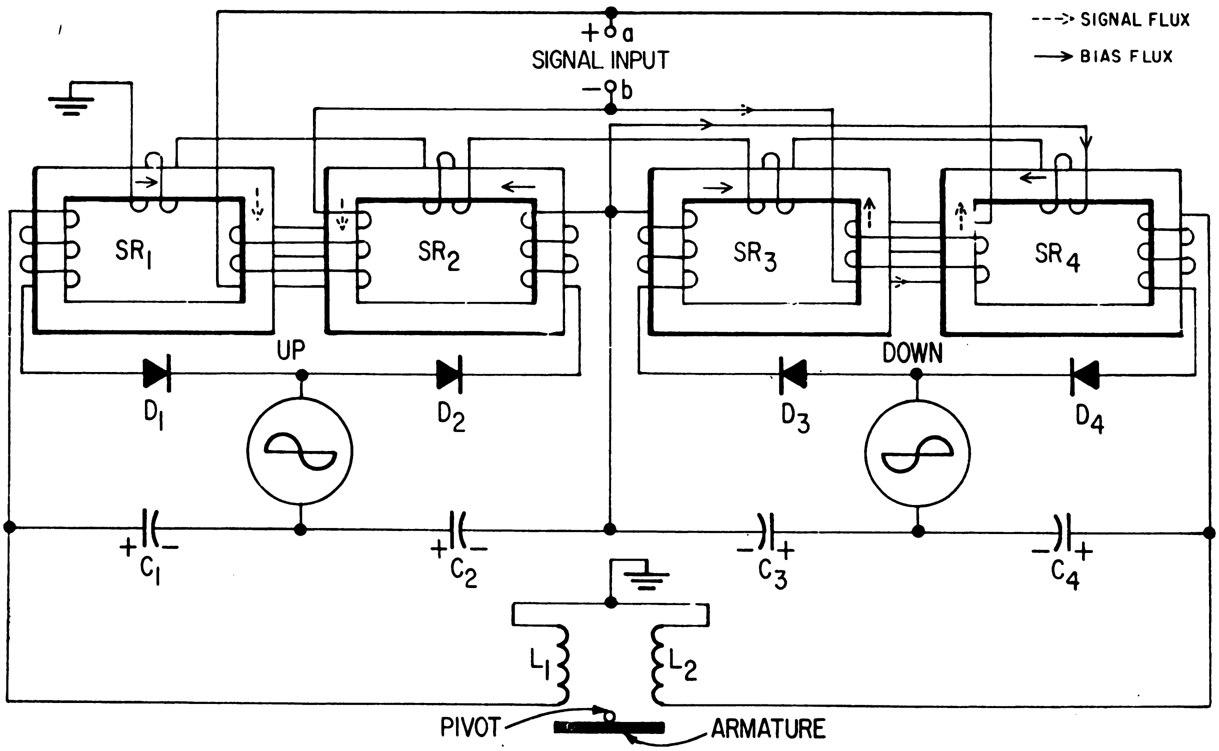


Figure 3-16.—Typical magnetic servo amplifier.

Control signals are applied to points a and b (fig. 3-16) only when an error occurs in missile flight, and the resulting current flow in the control coils may be either positive or negative depending on the direction of the missile error. Under zero-error, or static conditions, control current is zero and the control windings have no effect on the reactors.

Consider first the action of the circuit under static conditions in which a bias flux is established and the four capacitors are charged. Each of the two a-c sources is associated with two rectifiers and two capacitors to form a voltage doubler. In the first half-cycle of supply voltage, current flows in the load windings of reactors SR_1 and SR_3 so that the cores are driven toward the saturation point on the magnetization curve. Current flowing through the supply winding of SR_1 charges C_1 to a voltage almost equal to the peak value of the applied wave, while current through SR_3 charges C_3 similarly. A portion of the current conducted by the latter reactor also flows in the bias winding and produces a unidirectional flux in all four cores.

During the second half-cycle, reactors SR_2 and SR_4 go into conduction and charge C_2 and C_4, respectively. Some of the current through SR_2 is drawn through the bias winding in the same direction as the corresponding current in the first half-cycle; and thus, the bias is established by conduction in both the UP and DOWN sections. The arrangement is then self-biasing; and because of the filtering action of the capacitors, the bias level remains substantially constant. Note that the bias circuit is somewhat similar in operation to feedback but differs in that a change in signal does not cause a change in bias.

POWER-SUPPLY REGULATOR

The power supplies of most missile systems must meet certain basic requirements which include ruggedness, long life, and freedom from excessive maintenance problems. To meet these requirements, the development of power-supply equipment has resulted, in many cases, in the elimination of the electron tube as the chief cause of failure. The magnetic amplifier has been used to replace the complex arrangements usually necessary for good voltage regulation; and the solid-state power diode is often employed instead of the fragile vacuum tube. An example of a circuit with these components is shown in figure 3-17.

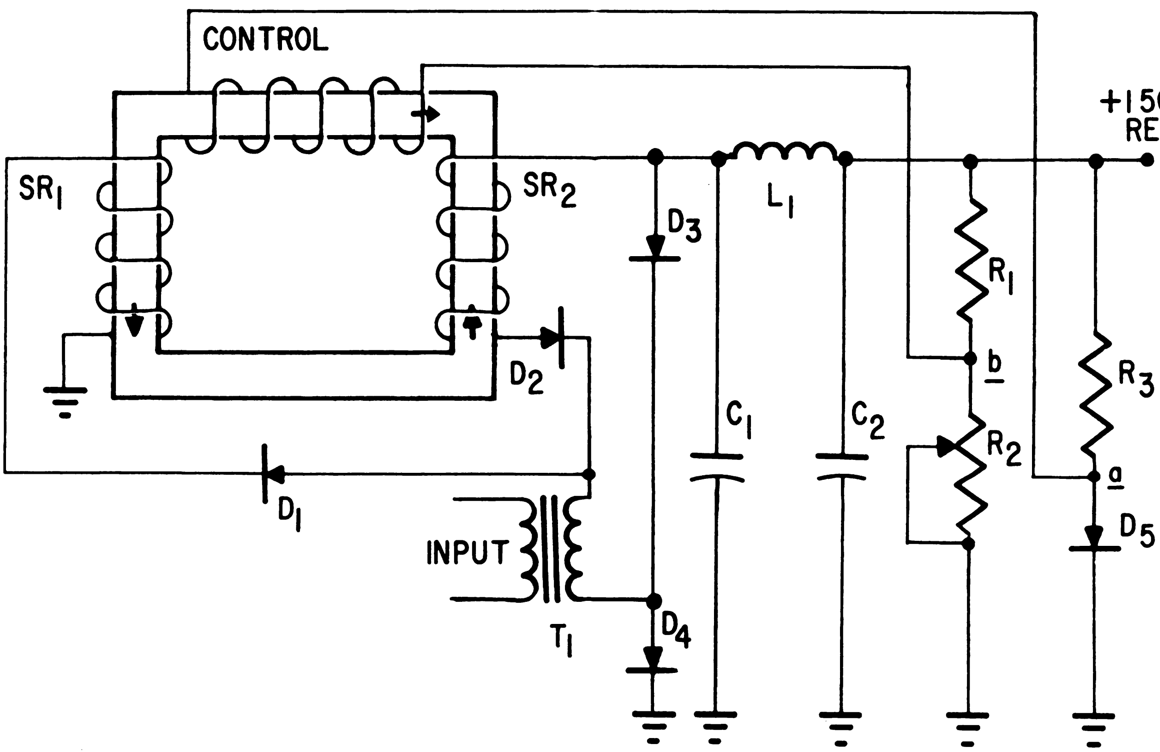


Figure 3-17.—Power supply with magnetic-amplifier regulator.

The circuit is a conventional full-wave bridge rectifier utilizing a magnetic amplifier to control the output and also a Zener diode as a part of the regulating system. The latter element is a solid-state equivalent of the gaseous regulator tube and maintains a constant voltage across the terminals regardless of variations of the current it conducts, within the specified operating range. In the schematic shown (fig. 3-17), the connection of the Zener diode is the reverse of that of an ordinary rectifying diode, since in this example it is the inverse breakdown voltage characteristic which is employed for regulation.

Current flow (fig. 3-17) during one half-cycle is through the load, through L_1, D_3, the secondary of T_1, and D_1, then returning to ground through reactor SR_1. During the other half-cycle, the current flows through the load, L_1, SR_2, D_2, the secondary of T_1, and D_4 to ground. In addition to the load current, there is conduction through D_5 and R_3 and also through R_2 and R_1.

The control winding of the magnetic amplifier is energized by the voltage between the junction of R_1 and R_2 and the upper terminal of the Zener diode, D_5. When the output voltage is of the proper value, the potential across the control winding (and therefore the current through it) sets the magnetic bias of the reactors at the operating point, which is well up on the magnetization curve to obtain a high percentage of the source voltage.

If the output voltage tends to rise, the voltage at point a remains constant due to the action of the Zener diode; but the voltage at point b increases. This causes a change in the current flowing in the control winding so that the bias point is shifted to a value that results in lower conduction in the load coils. As a result, the voltages across SR_1 and SR_2 are increased and the output voltage decreases.

When the output voltage tends to decrease, the potential at point b falls with respect to that at point a and the control current changes the bias to a point of higher conduction. This lowers the voltage drops across the a-c coils of the reactors and increases the value of the output. Capacitors C_1 and C_2, together with L_1, are connected to form a pi-section filter which smooths the output to give a nearly pure d-c voltage. Resistor R_2 is adjustable, being set to the value for optimum operating voltage in normal use. It also provides a means for making adjustments to compensate for any changes that occur in the circuit components.

Other Applications of Magnetic Amplifiers

In addition to the basic units described above, magnetic amplifiers are often applied in the following types of missile circuitry:

Electrical computers, which add, subtract, multiply, divide, integrate, and differentiate electrical quantities.

Multivibrators of the monostable, bistable, and free-running types, used as square-wave generators.

Sweep generators in trigger and pulse forming circuits in missile test equipment.

ADVANTAGES AND DISADVANTAGES

The principal advantages of the magnetic amplifier in the missile field are ruggedness and long life, and the resulting decrease in component failures. Magnetic circuits do much to lessen the maintenance and repair load by elimination of fragile filaments; while at the same time, they have the desirable feature of almost zero warmup time.

The reduction in heat resulting from the elimination of filaments and the plate dissipation common to vacuum tubes lessens the need for blowers and other cooling equipment. In most cases, high-voltage d-c power supplies are not required, which is an important safety consideration. Typical amplifiers are capable of high individual stage gains of voltage or power; impedance matching can be effected easily; and the magnetic units are usually constructed so that they can be isolated from other parts of the equipment such as output circuits.

On the other hand, the bulkiness of magnetic equipment is frequently a deterrent to its use, since most reactors designed for operation on 60 cycles are much heavier and larger than their electronic counterparts. The trend toward use of 400- and 800-cycle power frequencies, however, has helped materially in reducing the size and weight of the magnetic units.

Among the disadvantages of magnetic amplifiers is the inherent time lag typical of most reactors; and this characteristic alone often restricts their usefulness. In addition, distortion is a limiting factor, not only because of the inability of the amplifier to reproduce the input waveforms with precision, but also because of the harmonic frequencies generated by distortion. These often make it necessary to employ shielding so that nearby equipment is not subjected to undesirable radiation.

While magnetic amplifiers operate efficiently within a fairly wide range of temperatures—about -60° to 212° F.—they have limitations with regard to temperature. Deviation from the normal range, either above or below, may alter the magnetic properties of the core materials and materially change the operating characteristics of the amplifier. When dry-disk rectifiers are used as associated circuits elements, as is the case in many units, their operation may likewise be affected by temperature extremes.

Although magnetic amplifiers often serve to replace vacuum tubes, they are not as versatile; and in numerous cases, the magnetic unit is used in conjunction with the electronic amplifier to utilize the major advantages of each. Usually, vacuum tubes are more suitable in the earlier stages of signal sequence, deriving the required voltage gains with minimum distortion; while magnetic amplifiers are used principally in the last stages to develop high power outputs at comparatively low d-c voltage levels.

In general, the advantages of the magnetic amplifier outweigh the disadvantages; and in the missile field, the use of these devices as components of missile systems and missile test equipment is becoming rapidly more prevalent.

QUIZ

1. One of the oldest forms of magnetic amplifiers is the
   a. saturable reactor
   b. variometer
   c. autotransformer
   d. fluxometer

2. Basically a magnetic amplifier consists of a controlled variable inductance in series with a/an
   a. a-c power supply and a load
   b. d-c power supply and a load
   c. inductance and a control winding
   d. d-c power supply and a control winding

3. The permeability of a substance is a measure of the
   a. opposition it exerts to passage of magnetic lines of force
   b. ease with which it conducts magnetic lines of force
   c. force needed to magnetize a core material
   d. number of lines of force present in the core material

4. The inductive reactance of a coil with a magnetically saturated core is
   a. maximum
   b. zero
   c. infinite
   d. minimum

5. The reluctance of an air core
   a. varies with the applied magnetomotive force
   b. varies inversely as the number of turns on the coil
   c. varies directly as the number of turns on the coil
   d. remains constant regardless of the applied magnetomotive force

6. The purpose of a three-legged core is to
   a. increase the inductance of the control winding
   b. reduce unwanted coupling between control and output windings
   c. improve transformer action between windings
   d. eliminate the necessity of a bias winding

7. Resetting in a magnetic amplifier is the process of
   a. readjusting the position of the output winding
   b. compensating for overloads
   c. positioning the residual magnetic flux
   d. readjusting the balance winding

8. How is it possible to control the inductance of a given coil?
   a. By controlling the permeability of the core
   b. By increasing the current flow in the coil
   c. By increasing the voltage applied to the coil
   d. By controlling the frequency applied to the coil

9. An electronic method of controlling the permeability of a coil core is obtained by
   a. decreasing the number of turns on the coil
   b. increasing the number of turns on the coil
   c. using a properly designed magnetic coil material
   d. saturating the core with a d-c or properly phased a-c voltage

10. Magnetic amplifiers provide large amounts of power or voltage gain, but require
    a. no cathode heating
    b. d-c operating potentials only
    c. no a-c operating potentials
    d. mounting with shock insulators

11. Saturable reactors contain at least two coils wound on a common core. One coil is for d-c control voltage; the other coil is an element
    a. in parallel with a-c load circuit
    b. in series in a d-c load circuit
    c. in series in a a-c load circuit
    d. in the bias circuit

12. In a fundamental magnetic amplifier where the effective permeability of the inductance coil is controlled by inserting or removing the core, when the core is completely within the winding, the
    a. voltage drop across the coil is minimum
    b. load current flow is at maximum
    c. voltage drop across the coil is maximum
    d. inductive reactance of the coil is minimum

13. The core of a magnetic amplifier is said to be saturated when further increase of the magnetizing current produces
    a. a large increase in the total flux
    b. a small increase in the total flux
    c. no increase in the total flux
    d. a lower reluctance

14. The effect of positive feedback in a magnetic amplifier is to
    a. decrease sensitivity to changes in control current
    b. increase stability of the amplifier
    c. decrease the response time of the amplifier
    d. increase sensitivity to changes in control current

15. Among the basic characteristics of any magnetic amplifier is a lag or time delay; this is due to the
    a. high frequency voltage needed in the output
    b. action of the inductance-resistance circuits of the amplifier
    c. high current requirements of the control winding
    d. transformer coupling between the windings of the amplifier

16. The time constant of a particular amplifier is
    a. directly proportional to the number of turns in the load winding
    b. inversely proportional to the source frequency
    c. directly proportional to the source frequency
    d. inversely proportional to the number of turns in the control winding

17. In an audio-frequency magnetic amplifier, to obtain a favorable amplification factor, the a-c source should supply a frequency which is
    a. higher than the highest frequency of the audio input
    b. lower than the lowest frequency of the audio input
    c. lower than the hgihest frequency of the audio input
    d. equal to a normal line frequency

18. In a magnetic amplifier, transformer coupling is
    a. necessary for proper operation
    b. disregarded as a design feature
    c. maximized in the best designs
    d. undesirable for best operation

19. In figure 3-6 where must the control potentiometer be positioned to give maximum saturation of the core material?
    a. At the negative end of the voltage divider
    b. At the midpoint on the voltage divider
    c. Between the midpoint and the positive end of the voltage divider
    d. At the positive end of the voltage divider

20. If the core material has hysteresis characteristics that result in a rectangular-shaped B-H curve, it may be necessary to
    a. remove bias to retain control
    b. decrease the control voltage
    c. bias the core to retain control
    d. decrease the frequency of the a-c source

21. A two winding magnetic amplifier with the load winding in series with an a-c source and a load resistance can be made more efficient by the addition of a/an
    a. a-c source in the control winding
    b. low-impedance winding in the load circuit
    c. large number of turns on the control winding
    d. half-wave rectifier in the load circuit

22. The action of the half-wave rectifier in the load circuit of a two winding magnetic amplifier can be interpreted as a/an
    a. external feedback
    b. self-bias circuit
    c. internal feedback
    d. additional control element

23. It is possible to improve many of the operating characteristics of a magnetic amplifier by
    a. an external feedback current
    b. reducing the frequency of the a-c source
    c. removing the bias winding
    d. increasing the voltage of the a-c source

24. One method used to make a magnetic amplifier circuit more sensitive to changes in control current is to
    a. use degenerative feedback
    b. increase linearity of the magnetization curve
    c. decrease the response time
    d. use positive feedback

25. The principal advantages of the magnetic amplifier in the missile field are
    a. ruggedness and long life
    b. light weight and economy
    c. good frequency response and long life
    d. ruggedness and economy

CHAPTER 4

SPECIAL ELECTRONIC CIRCUITS

It is the purpose of this chapter to illustrate and discuss representative examples of the electronic circuits employed in the guidance and control sections of most air-launched missiles and in the associated test equipment. Knowledge of electronic equipment is one of the primary requirements of the missileman engaged in repair and testing of missile units, which include those used for such diverse functions as computing, timing, servo control, target detection, and radar ranging.

Considerable supplementary reading by the trainee is necessary in the study of the following pages. This material can be found in *Basic Electricity*, NavPers 10086 and in *Basic Electronics*, NavPers 10087. Chapters of the companion texts are referenced in appropriate parts of the various discussions. The circuits described include wave shapers, phase-shifting networks, filters, and impedance matching devices. Considerable space is also devoted to vacuum-tube limiting circuits, clampers, and pulse counters, all of which are employed in many types of missile equipment.

In the study of these circuits, the waveforms of the applied or generated signals are often of primary significance; and hence it is desirable to begin with a discussion of typical wave patterns and the general methods used in their analysis.

Analysis of Periodic Waveforms

A periodic wave is a pattern of voltage or current variation which is repeated at regular intervals of time. Typical examples are illustrated in figure 4-1. The upper drawing shows the basic type of variation, the sine wave; and in the lower drawings, nonsinusoidal waves are illustrated that are frequently employed in missile equipment.

Two general methods are used in the study of nonsinusoidal signals and the circuits designed to generate or amplify them. The first is harmonic analysis, in which a given nonsinusoidal wave is considered as being composed of many pure sine waves. The second method, called transient analysis, proceeds by considering the wave in question as a rapid change of voltage (or current) followed after a certain interval by a similar change. In the latter method, the values of the time constant of the circuit and the period of the applied wave are the principal factors from which the response of the circuit is determined.

HARMONIC COMPOSITION OF NONSINUSOIDAL WAVEFORMS

By the methods of wave analysis, it can be shown that any periodic waveform, regardless of complexity, can be constructed by combining a pure sine wave with other sine waves of different frequency, amplitude, and phase. The component wave with the same frequency as the nonsinusoidal pattern to be constructed is called the fundamental (or first harmonic). The other components are called simply the harmonics and are whole-number multiples of the fundamental. For example, the component frequency twice the fundamental is the second harmonic; while those three, four, five, and six times the fundamental are called the third, fourth, fifth, and sixth (and so on) harmonics. The sine wave shown in figure 4-1 is the fundamental component of all the nonsinusoidal waves below it. The compositions of these by combination of the various harmonics are illustrated in figures 4-2, 4-3, and 4-4.

A symmetrical square wave (fig. 4-2) is composed of a fundamental and a large number (theoretically infinite) of odd harmonics. As indicated in the drawing, the effect of the harmonics, when combined with the fundamental, is to reshape it to the balanced square form. Note that the harmonic components start in phase with the fundamental at the initial half-cycle; and if sufficient harmonics are added, the leading and trailing edges of the resultant are quite steep and the top of the wave is almost flat.

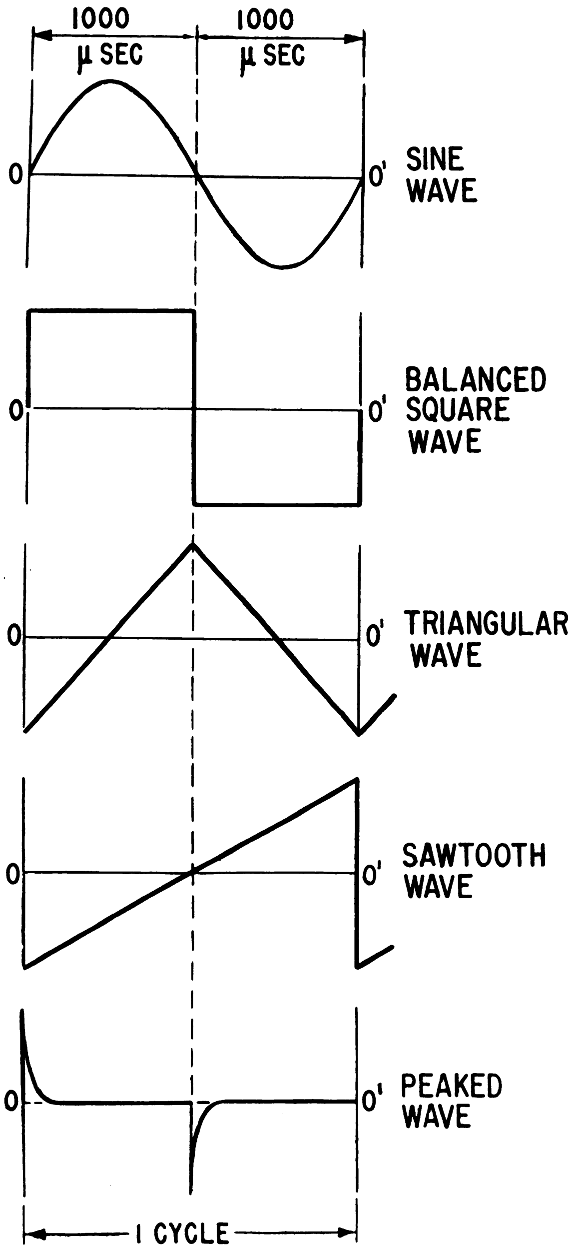
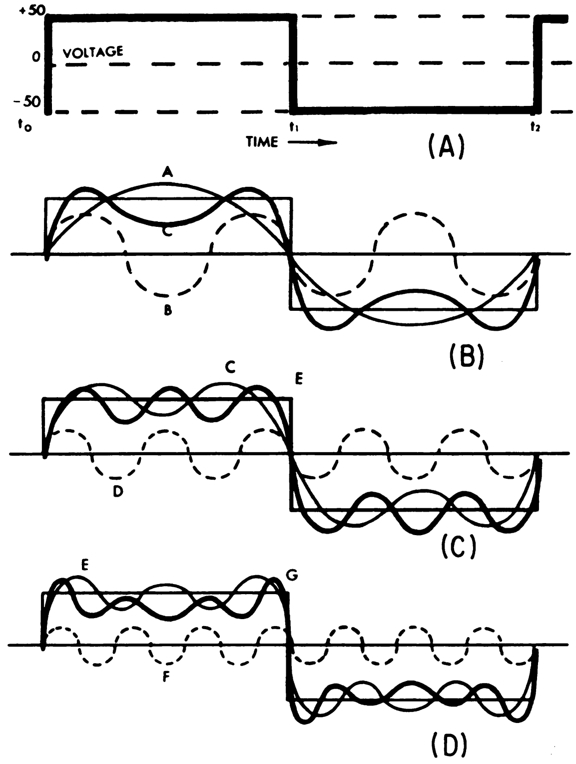


Figure 4-1.—Typical periodic waveforms.

The rectangular wave, a signal form of great importance in pulse-radar systems, is somewhat similar to the square wave since it consists of a narrow, flat-topped pulse with steep leading and trailing edges. It differs from the square pattern, however, in that the duration of the pulse is considerably less than the time interval between pulses, and also in that its composition requires both even and odd



A FUNDAMENTAL
B 3RD HARMONIC
C FUNDAMENTAL PLUS 3RD HARMONIC
D 5TH HARMONIC
E FUNDAMENTAL PLUS 3RD AND 5TH HARMONIC
F 7TH HARMONIC
G FUNDAMENTAL PLUS 3RD, 5TH AND 7TH HARMONIC

Figure 4-2.—Composition of a square wave.

harmonics. In addition, rectangular pulses employed in practical applications often contain d-c components which set the extremities of the signals at some desired voltage level.

Figure 4-3 illustrates the composition of a sawtooth wave which involves the use of both even and odd harmonics. The sawtooth form results when the odd components start in phase with the fundamental and the even harmonics begin out of phase with it. In its usual form, the sawtooth wave is essentially a slow, linear rise in voltage from the initial value until a maximum voltage is reached from which there is an almost instantaneous drop to the initial voltage.

The peaked wave, one of the most useful of nonsinusoidal variations, is employed as a trigger pulse in many types of control equipment. The composition, shown in figure 4-4, shows that it is made up of odd-order harmonics

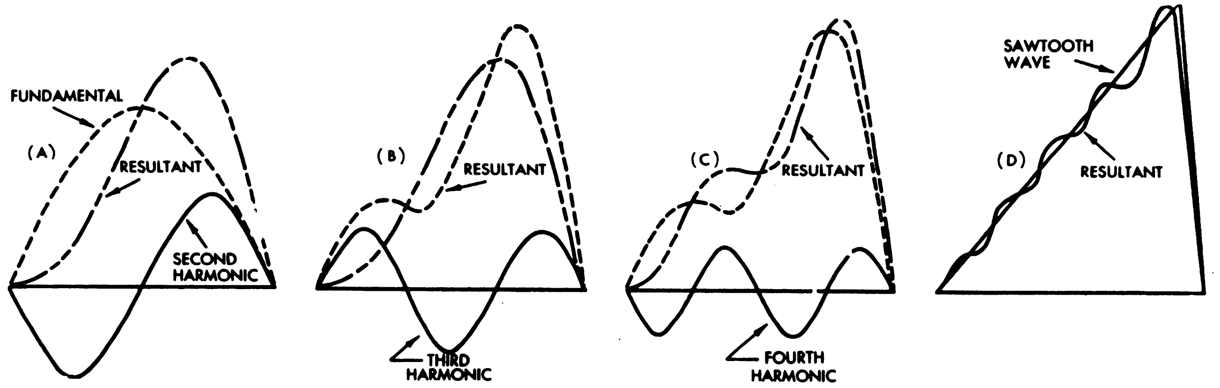


Figure 4-3.—Composition of a sawtooth wave.

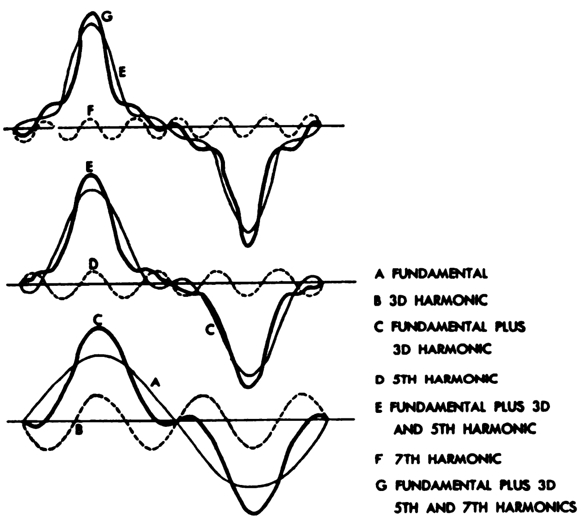


Figure 4-4.—Composition of a peaked wave.

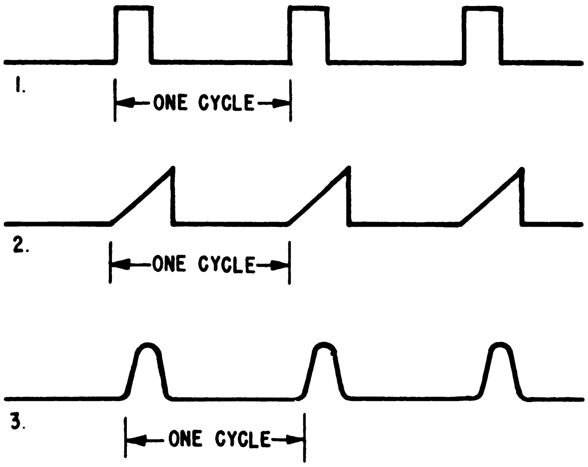


Figure 4-5.—Waves with unequal alternations.

only, as in the case of the square wave. The difference of the two resultants is the result of the phase relations of the component waves. To produce the peaked form, the harmonics in the series consisting of the third, seventh, eleventh, and so on, must start out of phase with the fundamental; while those in the series containing the fifth, ninth, thirteenth, etc. all start in phase with the fundamental. The maximum amplitude of the resultant wave increases as the total number of harmonics is increased; and as in the composition of the square wave, the steepness of the waveform is improved as more high-order harmonics are added.

Most of the waveforms shown above are symmetrical; that is, each cycle is divided into two equal alternations of opposite polarity. In addition to signals of this type, unsymmetrical waves are often employed in missile applications in which the alternations are of one polarity only, or else are unequal with respect to the zero level. Some of these forms are shown in figure 4-5. Analysis of these reveals that each contains a d-c component that establishes the average value of each cycle at some value other than zero. With the exception of this component, unsymmetrical variations contain the same types of components as symmetrical waves—a fundamental and a group of higher-order harmonics, all of which are pure sine waves.

When signals of the type represented in figure 4-5 are passed through coupling capacitors or through transformers, the d-c component is blocked and does not appear in the output, the average value of which then becomes

zero. When it is necessary to retain the previous reference level, the stage following the coupling network must contain clamping circuits, or d-c resotrers. The effect of these circuits is to reinsert the d-c component blocked by the coupling device by restricting output-signal swings either above or below some appropriate value. Typical examples of clamping circuits are discussed in a subsequent section.

If the problem is simply one of passing the nonsinusoidal wave through amplifiers and coupling networks without loss of shape, then the principal requirement is that the frequency response of the given circuit be adequate. It is apparent from the compositions illustrated in the foregoing paragraphs that any signal of this form is equivalent, not to a single frequency, but to a combination of many different components. A circuit capable of coupling a square wave, for example, without loss of waveform is said to be "flat" over the range of frequencies containing the principal harmonics. Such a circuit gives uniform response to the various components present and passes each without appreciable phase distortion.

The perpendicular leading and trailing edges of nonsinusoidal waves such as theoretically perfect square or rectangular pulses cannot be passed through practical circuits without distortion. However, it is possible to construct circuits capable of coupling or amplifying these signals with very little change in waveform indicating a frequency-response characteristic curve that is flat over a range of several megacycles. Square waves are often employed to check the frequency response of circuits under test. In this case, lack of proper response is indicated by output waves with rounded corners, wave tops that are not flat, and by pronounced slopes indicating abnormal values of rise and decay times.

The information provided by harmonic analysis is useful for purposes of design, for studying the action of certain basic circuits such as push-pull amplifiers, for checking frequency response, and for making many kinds of microwave measurements. However, when studying the operation of circuits containing resistance-capacitance and resistance-inductance combinations, it is often more convenient to proceed from the standpoint of transient analysis.

TRANSIENT VOLTAGES IN R-C AND R-L CIRCUITS

The term transient is applied to voltages (and currents) that are present in circuits following changes of the input and which decay more or less rapidly with time. The transient condition is distinguished from the steady-state, the condition of the circuit after the transient voltages and currents have disappeared and full response has been reached with the new input. Transient voltages in R-C and R-L circuits rise and fall in accordance with fairly simple rules involving the time constants of the combinations; and by knowledge of these, it is often possible to analyze the operation of complex vacuum-tube stages by means of equivalent circuits containing batteries, switches, and the appropriate load elements.

The circuit theory upon which transient analysis is based is given in *Basic Electricity*, NavPers 10086, chapter 8. The trainee will find the required information in the following sections of the referenced chapter:

Growth and Decay of Current in an R-L Series Circuit, page 219,
L/R Time Constant, page 222,
R-C Time Constant, page 236, and
The Universal Time Constant Chart, page 238.

These sections pertain to d-c transients in R-C and R-L networks. It is necessary to extend the discussion to cover a-c transient actions and to develop the theory of long and short time-constant circuits.

Long and Short R-C Circuits

When nonsinusoidal waves are applied to R-C circuits, the resulting response is determined by two principal factors, the time constant of the combination and the frequency of the applied signal. On page 236 of *Basic Electricity*, the time constant is defined as the product of R in ohms by C in farads. This product is equal to the time in seconds required to make certain percentage changes in the capacitor voltage: to increase it by 63 percent (approximately) of the total possible increase or to decrease it to 37 percent of the total possible decrease in voltage. This relation is valid with both d-c and a-c inputs. In the latter case, a given R-C circuit may be classified as long, short, or intermediate, depending upon the value of the time constant relative to the time duration of the applied pulse.

It will be recalled that the period of an a-c signal, or the time required for one complete cycle, is given by the equation

$$\text{Period} = 1/F,$$

where F is the frequency in cycles per second. When considering pulse inputs, the time interval of importance is usually the half-period rather than the full 1/F value. Consider, for example, the positive square pulses shown in figure 4-6. The interval from A to B is the time during which the capacitor is charging toward the positive maximum, and that from B to C is the time during which it discharges. The complete cycle then is made up of two distinct pulses. The time of each is called the pulse time; and for a balanced wave is defined by the formula

$$\text{Pulse time} = 1/2F$$

where F is again in cycles per second. It is now possible to define the various classes of R-C circuits in terms of this quantity and the time constant in the following manner:

Long R-C circuits are those with time constants equal to or greater than 10 times the longest pulse time of the applied wave.

Short R-C circuits are those with time constants equal to or less than 1/10 the shortest applied pulse time.

Intermediate R-C circuits have time-constant values between these limits, a typical case being an R-C time equal to one-half the period of the input.

Long R-C Circuit Action

The characteristic action in long and short R-C combinations with square waves applied is indicated by figures 4-6 and 4-7. In the former, the time constant is equal to 0.1 microfarad times 100,000 ohms, or 10,000 microseconds. The frequency of the 100-volt positive pulse input is 2.5 kilocycles; hence, the pulse time (1/2F) is equal to 200 microseconds. Since the time constant is more than ten times the pulse time, the circuit responds as a long R-C; and therefore, the capacitor can charge or discharge only a very small amount during each applied pulse.

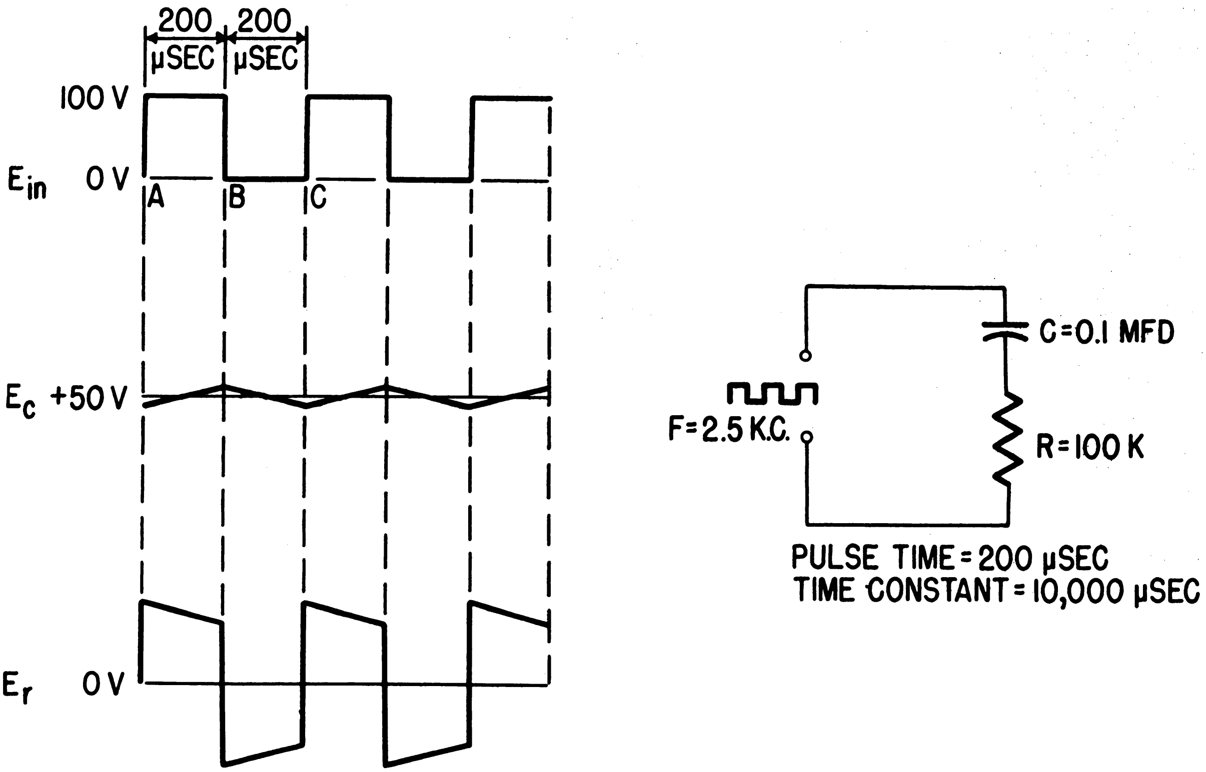


Figure 4-6.—Square wave applied to a long R-C circuit.

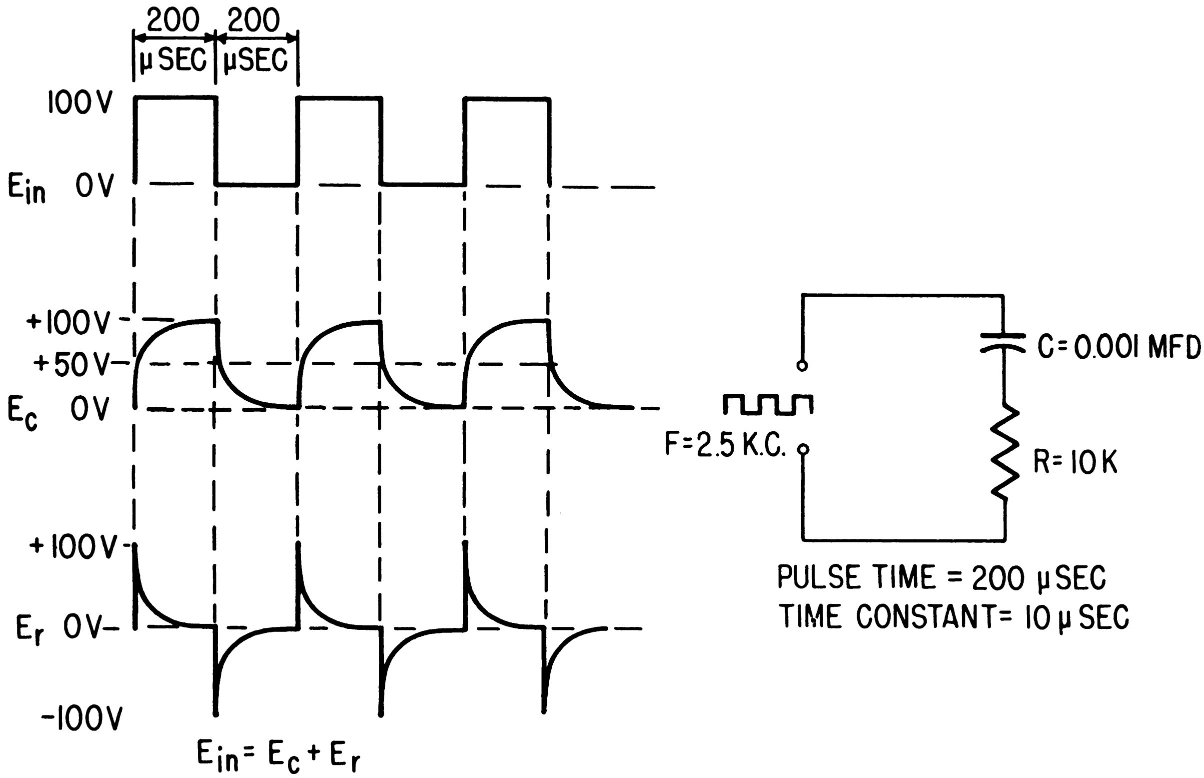


Figure 4-7.—Square wave applied to a short R-C circuit.

Consider first the charge developed by the capacitor (fig. 4-6). After the input is first applied, several cycles are required before the capacitor voltage reaches the final condition. When this condition is attained, the capacitor charge then changes by very small amounts during each pulse; and the capacitor voltage then varies about an average value equal to the d-c component of the applied wave. With the conditions illustrated, this potential is equal to positive 50 volts and is the value that would be indicated by a d-c voltmeter attached to the capacitor terminals.

Consider next the waveforms developed by the long R-C circuit shown in figure 4-6. The voltage across the resistor (E_r) is at any instant the difference of the input voltage (E_{in}) and the capacitor voltage (E_c). Since the capacitor can charge and discharge very little during each input pulse, E_c remains substantially constant; and almost all the applied pulse then appears across the resistor. Hence, the resistor waveform is practically identical with the input wave; and since the capacitor develops the d-c component present in the input, the resistor voltage is pure a-c variation, swinging about a center value of zero.

Short R-C Circuit Action

Typical short R-C waveforms with square-wave input are illustrated in figure 4-7. Assume that the capacitance is now 0.001 microfarads and the series resistance is 10,000 ohms. The input signal is identical with that of the previous example so that the pulse time is 200 microseconds. The R-C time constant, 10 microseconds, is then considerably less than the pulse time so that the circuit action is "short."

The following facts are indicated by the waveforms in figure 4-7:

Since the capacitor voltage can change almost as fast as the input, a square wave with slightly rounded corners appears across the capacitor terminals. Note that this wave varies about the same voltage level as in the long R-C circuit but that the change in voltage is now much greater.

The resistor voltage (fig. 4-7), which is equal to the difference of the input and the capacitor

voltage, is a peaked wave swinging between the extremes of positive and negative 100 volts.

The general facts of importance with regard to the long and short R-C circuits can be summed up in the following statements:

1. The long R-C combination reproduces the input waveform with very little distortion across the resistor. The capacitor voltage is very small in amplitude and varies about an average value equal to the d-c component of the input wave.

2. The short R-C circuit develops the input waveform with slight distortion across the capacitor. The resistor voltage is considerably distorted with respect to the input waveform. (When sine waves are applied to short R-C circuits, the resistor voltage is a low-amplitude sine wave displaced in phase by almost 90 degrees. In this case, the distortion present is in phase rather than in waveform.)

R-L Transients

As explained in the discussion of the Universal Time Constant Chart in *Basic Electricity*, chapter 8, the action of the R-L combination with respect to current is similar to that of the R-C circuit with respect to voltage. The time constant of the R-L combination is given by the ratio L/R, where L is the inductance in henries and R is the resistance in ohms. For purposes of transient analysis, R-L combinations can be classified into the same types as the R-C circuit. Long R-L circuits are those with time constants equal to or greater than 10 times the applied pulse time; short R-L circuits are those in which L/R is equal to or less than 1/10 the pulse time; and intermediate circuits are those with time constants between these extreme values.

The general characteristics of long and short R-L circuits can be stated simply by the following rules:

1. The long R-L develops voltages that are similar to those in the short R-C circuit. The applied wave is reproduced substantially unchanged across the nonresistive element—in this case, the inductor. The voltage across the resistor is distorted either in waveform or in phase compared with the input.

2. The short R-L circuit is similar in action to the long R-C. The input wave is developed practically unchanged across the resistor. The voltage wave developed by the inductor is distorted with respect to the input.

Wave Shaping Circuits

Wave shaping circuits are used in missile radar systems and in servo components to convert nonsinusoidal waves of various types into pulses with different forms. These circuits contain R-C or R-L networks, usually in combination with vacuum tubes, which provide switching action or amplification. The process of wave shaping, however, occurs in the R-C or R-L network, which has a time constant of such value that the desired waveform appears as a transient voltage across one of the elements.

The two fundamental wave shaping networks are differentiators and integrators. In the usual forms, these are R-C combinations, although the R-L circuit is capable of providing either differentiation or integration. Integrators are frequently used in relay-control equipment and also in stages that develop sawtooth waves, triangular waves, and other types of variations with linear rates of change. The differentiator, which is usually a short R-C, is an essential part of peaking circuits, which convert rectangular pulses into narrow voltage spikes.

DIFFERENTIATING AND PEAKING CIRCUITS

The R-C Differentiator

A differentiating circuit produces an output amplitude that varies in proportion to the rate of change of the input. The input rate of change is indicated by the slope of the applied signal and may be positive, negative, or zero even though the signal may consist of variations in one polarity only. The process can be illustrated by the waveforms produced by the short R-C differentiator shown in figure 4-8. Consider the positive square pulses in (B). The leading edge of each pulse is a jump or rapid transition to maximum positive amplitude, and hence the rate of change is then positive. Following the initial jump, the wave is flat, and the rate of change is then zero. At the trailing edge, the voltage falls from maximum to minimum and thus exhibits a negative rate of change. As shown in the drawing, the differentiator produces a positive, zero, and a negative output, respectively, in response to these input variations.

Note that the output wave in (B) of figure 4-8 has a peak-to-peak amplitude that is twice

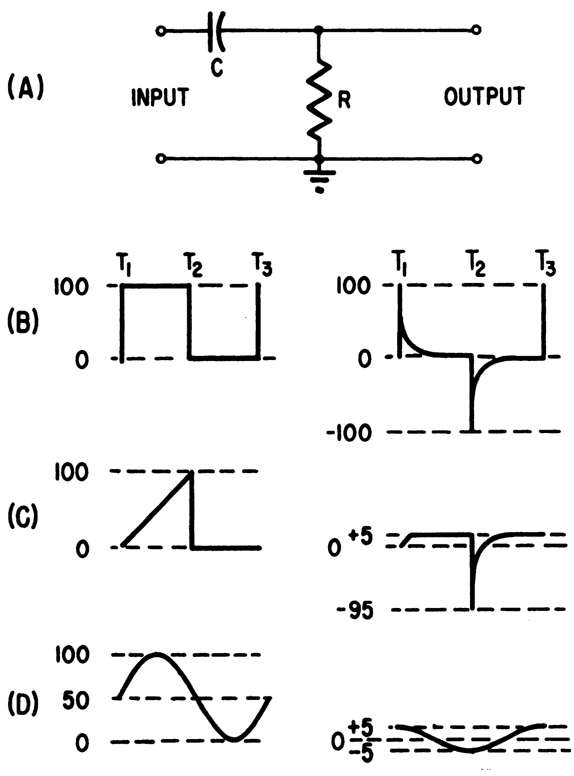


Figure 4-8.—R-C differentiator with input and output waveforms.

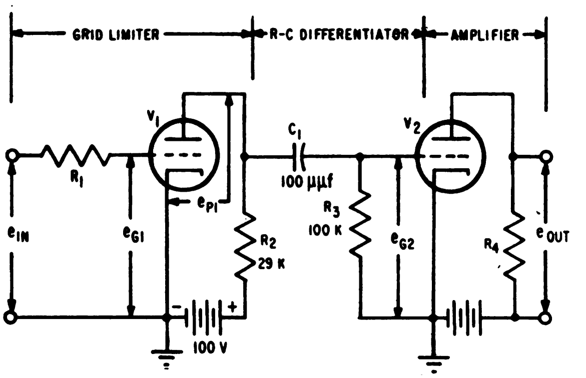


Figure 4-9.—Application of R-C differentiator in a peaking circuit.

the maximum applied voltage and that the peaks coincide with maximum change of the input, the directions of which determine the output polarity. As shown in (C), a sawtooth input results in an output that combines a rectangular pulse with a peaked wave. The first half-cycle results from the slow, linear rise of the applied sawtooth. The negative-going spike (corresponding to the sudden change from input maximum to minimum) results from the high negative change rate. Thus, the greater the slope of the applied wave, the greater the output amplitude.

The drawing in (D) of figure 4-8 illustrates the differentiated sine wave. Unlike nonsinusoidal inputs, the sine wave yields an output that is largely unchanged in shape but which is shifted by almost 90 degrees in phase. The amplitude of the differentiated wave is greatest when the input voltage is passing through the time corresponding to T_2, since the rate of change of the sine curve is maximum at this part of the cycle.

Peaking Circuits

In missile applications, the R-C differentiator is most frequently applied in circuits of the type shown in figure 4-9, a peaker that develops narrow trigger pulses. A detailed analysis of the overall operation of this circuit is given in the following pages. Figure 4-10 shows the principal waveforms present during operation; and figures 4-11 and 4-12 are equivalent circuits that are useful in explaining the fundamental actions involved.

The peaking circuit (fig. 4-9) produces trigger pulses by distorting the input rectangular waveform in such a way that the pulse time of the output wave is shortened and the leading edge is made practically vertical. The input voltage (fig. 4-10) has a half-period of

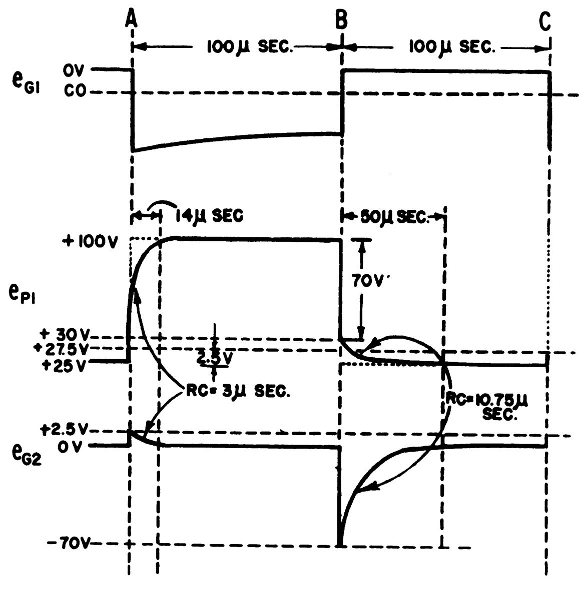


Figure 4-10.—Peaker circuit waveforms.

100 microseconds. It drives tube V_1 beyond cutoff during negative swings and maintains the grid at approximately ground potential during positive half-cycles by the process of grid limiting (discussed in another section of the chapter). The waves designated as e_{g1} and e_{p1} in figure 4-10 represent grid and plate voltages, respectively, of tube V_1; voltage e_{g2} is the grid voltage of V_2. The dotted waveform indicates the shape of e_{p1} with the differentiator network disconnected.

The maximum value of e_{p1} is 100 volts, and the minimum value as determined by the tube characteristics is 25 volts. The plate circuit of V_1 is effectively an open switch during the half-cycle that the tube is at cutoff; and when conducting, the plate circuit resistance is equal to the static plate resistance of the tube, or approximately 10,000 ohms.

During the time preceding A in figure 4-10, V_1 is conducting and capacitor C reaches a charge of 25 volts. Since the value of e_{p1} is steady at this level, the grid voltage, e_{g2}, becomes zero. These voltage conditions are present at the instant V_1 is driven to cutoff (time A in figure 4-10) since the capacitor cannot change in charge instantaneously.

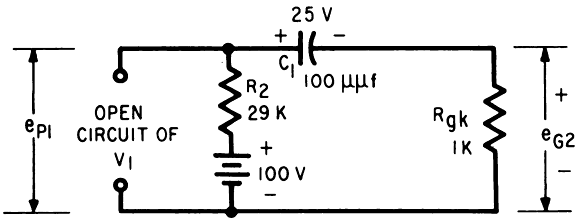


Figure 4-11.—Equivalent circuit of peaker with V_1 at cutoff.

With V_1 at cutoff, the circuit operation is that of the equivalent circuit shown in figure 4-11. During this half-cycle, the capacitor charges from the initial 25 volts to a final value of 100 volts. Since tube V_2 is normally biased to zero volts, any positive voltage applied to the grid causes grid current to flow, placing a grid-to-cathode resistance of 1,000 ohms in parallel with the grid resistor, R_3. The charging time constant then becomes

$$T \text{ (charge)} = R_{total} \times C$$

$$= (29 + 1) \times 10^3 \times 100 \times 10^{-12}$$

$$= 3 \text{ microseconds.}$$

The initial charging current flowing in the circuit is equal to the net voltage divided by the total resistance, or

$$i \text{ (initial)} = \frac{E}{R} = \frac{100 - 25}{(29 + 1) \times 10^3}$$

$$= 2.5 \text{ milliamperes.}$$

This current flows through the grid-to-cathode resistance of V_2 and causes an initial voltage drop of 2.5 volts.

Since the voltage across the capacitor at this instant is 25 volts, the initial value of voltage e_{p1} is 25 + 2.5, or 27.5 volts. The capacitor charges exponentially in a time determined by the 3-microsecond time constant, and voltage e_{g2} drops to zero in the same interval. The changes in voltages e_{p1} and e_{g2} are shown in figure 4-10 between points A and B.

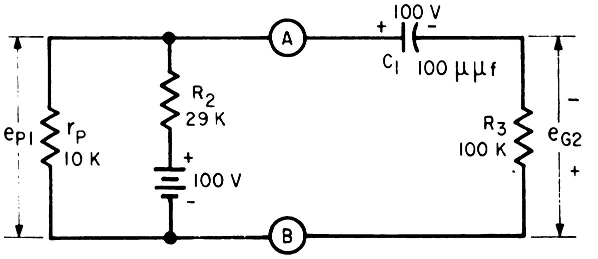


Figure 4-12.—Equivalent circuit of peaker with V_1 conducting.

At the end of the cutoff period of V_1, the potential across C is 100 volts. Thus, at the instant V_1 starts to conduct (time B in figure 4-10), the voltage drop across C remains at 100 volts and the full instantaneous change in the voltage e_{p1} appears across R_3 as e_{g2}. The equivalent circuit for the time interval during which V_1 is conducting is shown in figure 4-12.

During the conduction interval, C discharges from the initial value of 100 volts to the final value of 25 volts. As the grid of V_2 is normally at zero potential, any sudden decrease in e_{p1} is coupled through the capacitor and produces a negative potential at the grid of V_2. No grid current flows during this half-cycle; therefore, R_{gk} is effectively open circuited, and the discharge current must flow through R_3 to ground. The time constant during discharge is then

$$T \text{ (discharge)} = R_{total} \times C$$

$$= \left(\frac{10 \times 29}{10 + 29} + 100\right) \times 10^3 \times 10^2 \times 10^{-12}$$

$$= 10.75 \text{ microseconds.}$$

When V_1 is driven into conduction, the resulting circuit action consists of discharging C from 100 to 25 volts, a net change of 75 volts. The discharge current drawn from the capacitor is then

$$i\ (\text{discharge}) = \frac{E}{R}$$

$$= -\frac{75}{\left(100 + \frac{10 \times 29}{10 + 29}\right) \times 10^3}$$

$$= -0.7 \text{ milliampéres.}$$

This current flows in a direction opposite to that of the charging current, and hence the minus sign is used. Flowing through the grid resistor, R_3, it causes an initial voltage drop at the grid of V_2 of minus 70 volts, thereby providing the leading edge of the desired peaked wave. The plate voltage cannot drop instantaneously to the final value of 25 volts since the capacitor discharge rate is comparatively slow, being determined by the 10.75-microsecond time constant. It reaches this level by making a rapid jump from 100 to 30 volts, a drop of 70 volts, followed by a fairly slow fall to the 25-volt value. During this change, the grid voltage, e_{g2}, rises from -70 to zero volts, thereby forming the trailing edge of the peaked wave. These changes in plate and grid potentials are shown in figure 4-10 between points B and C, where again it is seen that the instantaneous change of e_{g2} is equal to that of e_{p1}, the plate voltage.

The shape of the plate waveform, e_{p1}, is modified somewhat by the peaking circuit to which it is fed. Theoretically, with the R-C circuit disconnected, the voltage variation at the plate of V_1 is a rectangular wave; but in the actual case, the corners are rounded due to the loading effect of the peaking circuit. The flow of grid current through V_2 during the charging period of the capacitor places the low grid-to-cathode resistance of the tube in parallel with R_3, producing a circuit with a very short time constant. Thus, a higher current flows and the loading effect is greater than is the case when the circuit resistance is higher and the time constant longer. The tube V_1 can be regarded as a square-wave generator with a fairly high internal resistance, since its terminal voltage varies considerably with variations in the load.

The loading effect of the differentiator can be reduced somewhat in applications requiring low output impedance by replacing the circuit of V_2 (fig. 4-9) with a cathode follower. Since the grid of a cathode follower can be driven highly positive without drawing grid current, the loading of the pulse generator is reduced and held essentially uniform throughout the complete cycle of operation.

THE R-C INTEGRATOR

The process of integrating an input wave is the opposite of differentiation. The integrating network produces an output wave with a rate of change, or slope, that is approximately proportional to the amplitude of the applied input signal. That is, constant positive input potentials result in output waves with positive rates of rise, while negative inputs cause downward sloping output waves. The variations of the output level are centered about a value equal to the average of the input signal. The output voltage must change slowly compared with input changes; and to accomplish this, the time constant of the R-C or R-L integrator must be long with respect to the applied pulses.

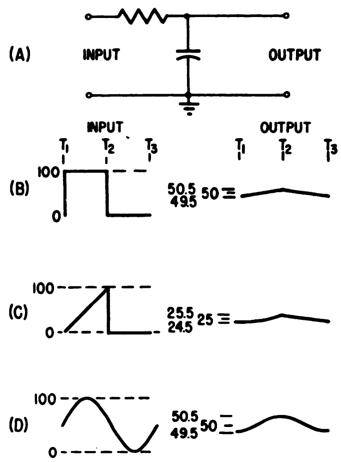


Figure 4-13.—R-C integrating network with input and output waveforms.

The basic integrator is a long R-C circuit connected as in (A) of figure 4-13, which also shows some typical integrated waveforms. In (B), the square-wave input results in a triangular wave. During the time interval from T_1 to T_2, the applied wave is at maximum positive level, and consequently, the output is a voltage that rises linearly, or with a constant slope. In the interval from T_2 to T_3, the input drops to minimum and the output potential falls

linearly at a rate approximately equal to the previous rate of rise.

A sawtooth wave applied to the integrator ((C) of fig. 4-13) gives an output that somewhat resembles the output in (B); however, the initial half is not so linear but curves upward with constantly increasing slope. This results from the fact that in the corresponding half of the input wave, the positive voltage is constantly increasing and each point on the input waveform requires a proportional value of rise rate in the integrated output. The first half of the output is a parabolic curve, while the second half between times T_2 and T_3 is identical with the resultant of the square wave. Note that in both (B) and (C), the output voltage alternates above and below a voltage equal to the average, or d-c component, of the input.

The integrator output with a sine-wave input is shown in (D) of figure 4-13. As in the process of differentiation, the basic form of the resultant resembles the input. Also, the amplitude is diminished and the phase is shifted with respect to the applied wave by almost 90 degrees, but in a direction opposite to that resulting from differentiation.

Phase Shifters

In addition to their many applications in wave shaping circuits, R-C and R-L combinations are widely used as phase corrective networks. In missile servo systems, these networks are employed to compensate for undesired phase shifts, to increase stability, and to improve system performance. R-C sections are essential parts of the feedback loop of the phase-shift oscillator, one of the basic circuits in telemetering equipment. Phasing networks are also required in many signal simulating units that generate test voltages for checking missile control devices.

Among the phase determining circuits common to these systems are phase splitters and variable phase shifters, examples of which are illustrated below. The operation of these depends upon the voltage and current relationships in R-C and R-L combinations which are summarized in the following list:

1. The current and voltage are in phase in a resistor.
2. The current leads the voltage by 90 degrees in a capacitor.
3. The current lags the voltage by 90 degrees in an inductor.
4. In a series circuit containing a resistor and a capacitor, the voltage across the resistor leads the voltage across the capacitor by 90 degrees.
5. In a series circuit containing a resistor and an inductor, the voltage across the resistor lags the voltage across the inductor by 90 degrees.

PHASE SPLITTING CIRCUITS

Representative phase splitting circuits are shown in figures 4-14 and 4-15. Each is a simple arrangement for developing two out-of-phase voltages from a single input. With applied sine waves, the R-C circuit (fig. 4-14) produces the voltages E_R and E_C which are displaced by 90 degrees. The phase difference results from the fact that the voltage across

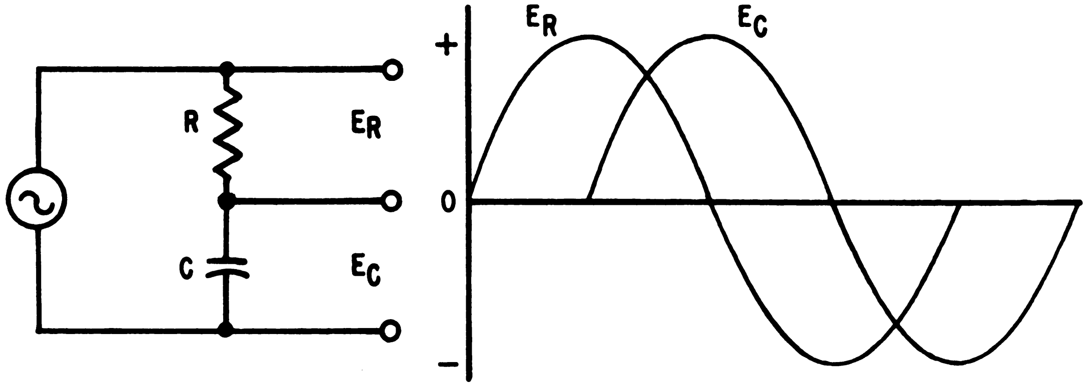


Figure 4-14.—R-C phase splitting circuit.

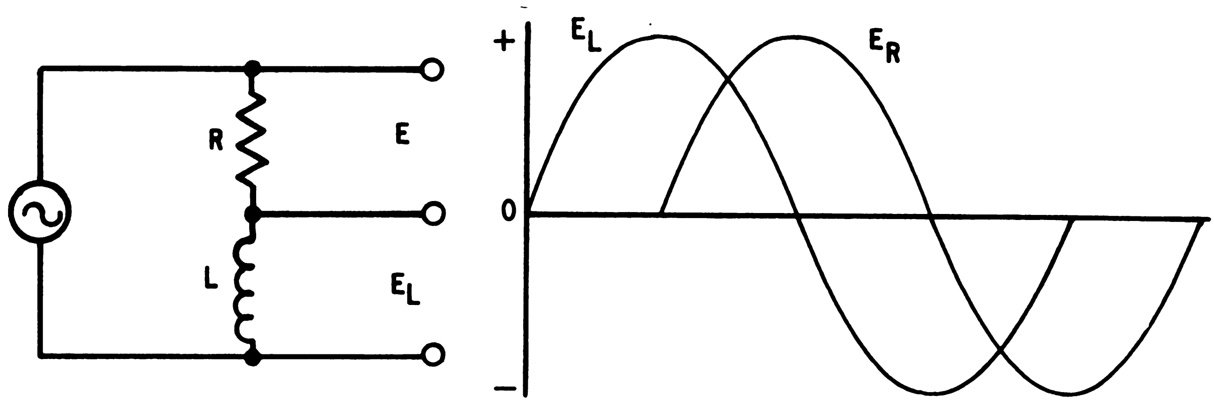


Figure 4-15.—R-L phase splitting circuit.

the resistor is always in phase with the current, while the voltage across the capacitor always lags the current by 90 degrees. A similar condition results when a resistor and an inductor are used (fig. 4-15), except that the direction of the phase shift is reversed. In an inductor, the current lags the inductive voltage by 90 degrees; and in the R-L circuit shown, voltage E_L must therefore precede the resistive voltage by 90 degrees since the latter is in phase with the current.

VARIABLE PHASE SHIFTING CIRCUITS

When it is necessary to vary the phase of an a-c signal over a particular range of angular values, phase shifters containing adjustable elements are employed. An example is the R-C circuit in figure 4-16. Waveforms and vector diagrams are shown which indicate the principal voltages.

If the rheostat (fig. 4-16(A)) is set so as to make the total resistance large compared with the capacitive reactance, opposition to current flow is mainly resistive and the effect of the capacitor is small. As a result, the current is almost in phase with the supply voltage. The voltage drop across the resistor is in phase with the current, and hence E_R is approximately in phase with the input voltage, as shown in (B) and (C). In this case, the capacitive voltage, the output, lags the supply voltage by almost 90 degrees.

If the total resistance (fig. 4-16(D)) is made small compared with the capacitive reactance, the current is then determined largely by the capacitor; and the resulting phase relations are as shown in (E) and (F). Since the current leads the supply voltage by nearly 90 degrees, the resistor voltage also leads the input by the same angle. The capacitor voltage, or output, is then nearly in phase with the applied voltage.

The conditions illustrated by the waveforms in figure 4-16 can be stated in general form as follows: If the output voltage is taken from the capacitor, the phase angle between it and the input varies with the amount of resistance in the circuit. With small amounts of resistance, the output is almost in phase with the input; while increasing the resistance has the effect of increasing the phase angle between the input and output waves.

The output voltage of the R-C phase shifter can also be taken from the resistor; however, the direction of the phase shift is then reversed compared with the circuit as described above. If the resistor is made the output element, increasing the resistance value brings the input and output waves nearer in phase; while decreasing the resistance causes a greater amount of phase displacement.

The R-L phase shifter (fig. 4-17) results when an inductor is substituted for the capacitor in the corresponding R-C circuit. The resulting phase relations of input and output voltages are indicated in parts (B) and (E) and also in the vector diagrams in (C) and (F) of the figure. In this case, the output wave is taken from across the coil and is at a leading phase angle with respect to the input so long as the circuit contains resistance. In the series combination, the current must lag the applied

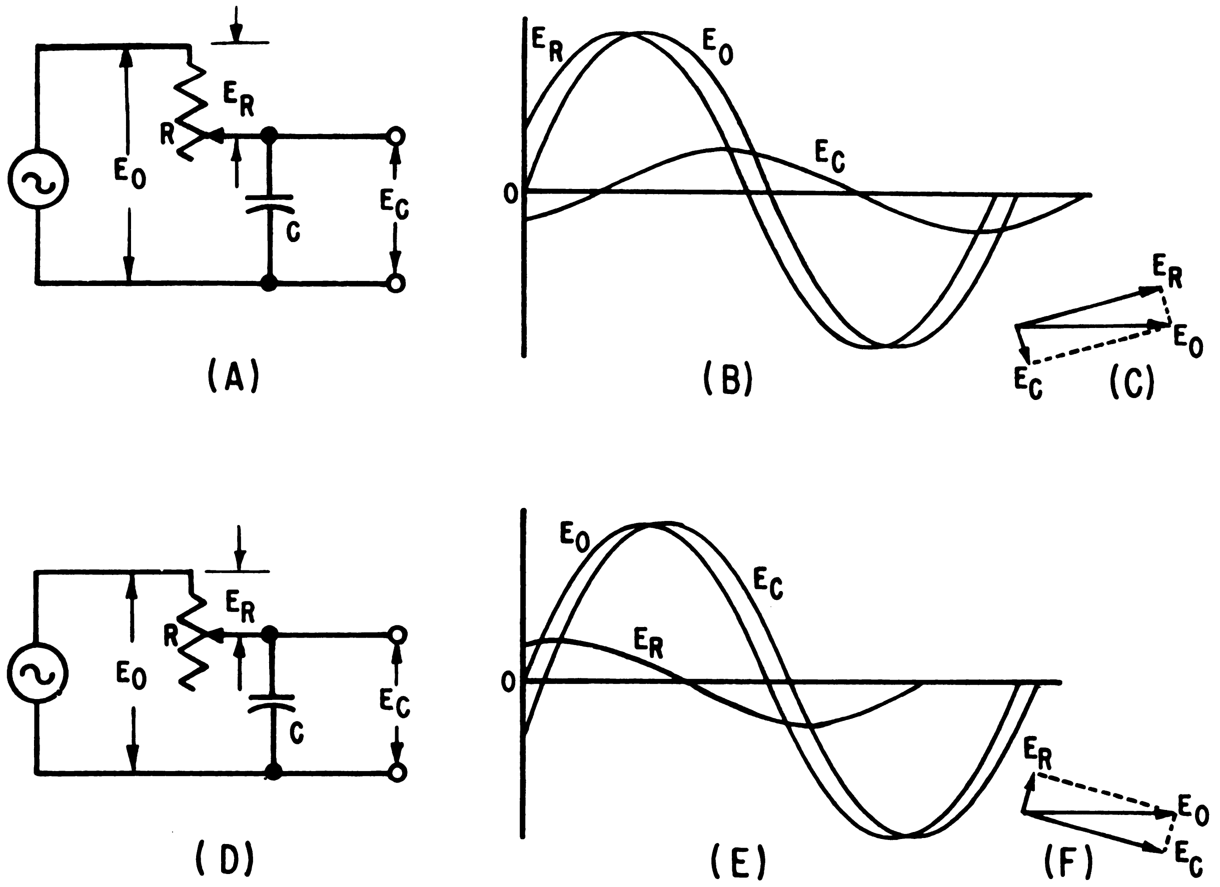


Figure 4-16.—Variable R-C phase shifting network.

voltage by some angle less than 90 degrees. Since the voltage across a coil leads the current through it by exactly 90 degrees, the output voltage must lead the input. An increase in the resistance of the circuit increases the difference in phase between input and output voltages. A decrease in the resistance brings the two waves nearer in phase.

Helmholtz Coils

One of the primary disadvantages of both the variable phasing circuits illustrated above is that the output voltages change in amplitude with changes in resistance. These networks are used mainly in applications where the phase of the signal is the primary concern and uniform amplitude is not essential. When testing missile servo components, it is often necessary that the test set provide simulated signals of constant amplitude but at phase angles variable over 360 degrees. An R-L or R-C phase shifter is inadequate for this purpose, and more elaborate phase shifting devices, called Helmholtz coils, are often employed.

These phase shifters are specialized transformers containing two sets of fixed primary windings and a pivoted secondary coil which can be rotated to any angular position with respect to the primary windings. An R-C phase splitting circuit converts the input voltage into two voltages separated by 90 degrees. These are applied to the primary coils, which are mounted so that the out-of-phase primary currents produce two magnetic fields. These combine to give a resultant field that rotates through 360 degrees. The resultant rotating field induces a voltage in the secondary which provides the output of the phase shifter. The position of the pivoted secondary winding can be adjusted with respect to the primary windings so that the output voltage is displaced by any desired angle up to and including 360 degrees.

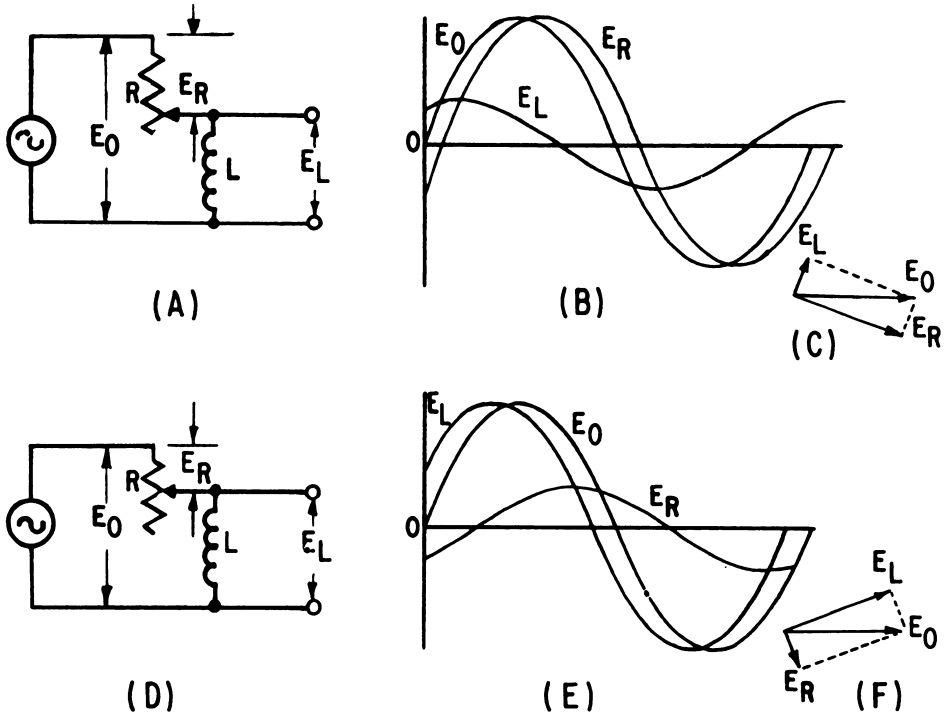


Figure 4-17.—R-L phase shifter.

Filter Circuits

Filters are required in almost all electronic equipment to select energy at certain desired frequencies and to reject energy at others. The fundamental filter types are band-pass, band-reject, low-pass, and high-pass circuits. These are usually made up by combining sections composed of inductance and capacitance; although in low-current circuits, R-C filters are also employed.

Band-pass and band-reject filters operate on tuned-circuit principles and are described in detail in *Basic Electronics*, chapter 1. Low-pass and high-pass filters in fundamental form, together with the corresponding frequency-current response curves are illustrated in figures 4-18 and 4-19.

As the name implies, the low-pass filter (fig. 4-18) passes with little attenuation those applied signals below a certain cutoff frequency and greatly attenuates all those above the cutoff value. Universal application of this circuit is made in electronic power supplies, most of which contain L-C filtering sections between the rectifier tubes and the output terminals. In this case, the function of the filter is to reduce ripple voltages at the source frequency and its harmonics, and to pass on to the output nearly pure d-c energy.

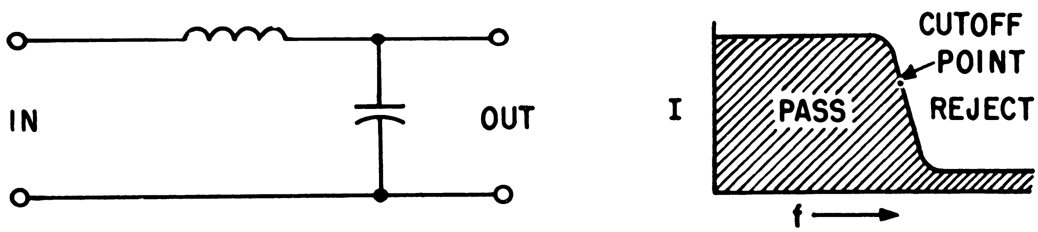


Figure 4-18.—Low-pass filter and response curve.

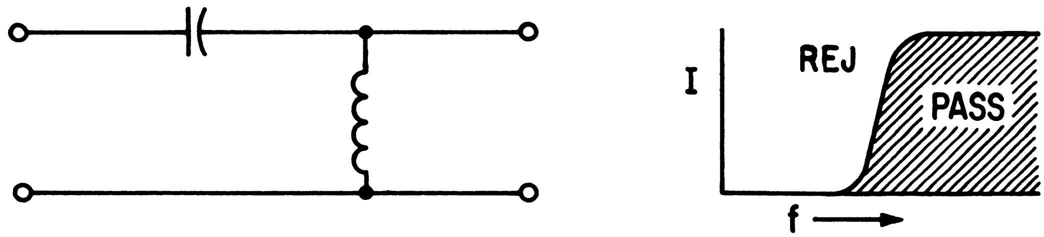


Figure 4-19.—High-pass filter and response curve.

An application of the low-pass filter, although in somewhat different physical form, occurs in the tail section of a typical radar-controlled beam-rider missile. The filter is located in the output of the detector and is composed of stray capacitance and lead inductance. A shunt path to ground is provided by the stray-capacitance, which in combination with the series inductance gives sufficient low-pass filtering to suppress the microwave carrier voltage and to pass only the comparatively low modulation frequencies which contain the guidance information.

As indicated by the response curve, the function of the high-pass filter (fig. 4-19) is the opposite of that of the low-pass circuit. Its design is such that input signals above a critical cutoff frequency are passed to the output with negligible loss, while those below cutoff are sharply reduced or eliminated altogether. Although it is not so frequently applied as the low-pass arrangement, this circuit is included in many servo electronic stages and in some video amplifiers. It is often employed in missile stages to suppress low-frequency voltages caused by resonant action of the overall system which in some cases is initiated by sudden motion of the weapon in pitch or yaw. A basic example of the high-pass filter in microwave equipment is the rectangular waveguide operating in the TE mode, which rejects input waves with half-wavelengths greater than the large dimension of the guide.

Impedance Matching Devices

Missile electronic circuitry contains many types of impedance matching devices. Among these are iron-core transformers, resistance pads, sections of waveguides and transmission lines, and vacuum-tube circuits such as the cathode follower. The application of all these as impedance matching networks involves a principle of fundamental importance in electric circuits. Stated simply, it is as follows: A load absorbs maximum power from the driving source if the load impedance is equal to the internal impedance of the source. This rule is valid for all types of circuits and at all frequencies. Hence, it can be demonstrated by the simplest of circuit combinations, a battery in series with a variable resistor. In addition, a table of values is required to show the current, voltage, and output power at different ratios of load resistance to battery resistance.

Figure 4-20.—Variable circuit illustrating resistance values for load matching.

The battery, or source of power (fig. 4-20), is assumed to have a 10-volt output under no-load conditions and an internal resistance (R_b) of one ohm. The load resistor, R_L, is adjusted to the values shown in table 4-1, causing the output power first to rise to a maximum and then to decrease. Note that the load current is low and the output voltage is high when the load resistance is large with respect to the battery resistance; while at low load-resistance values, the current is large and the output voltage is small. If the load is matched to the internal

Table 4-1.—Circuit action under varying load.

Load resistance (in ohms)	Load current (in amperes)	Load voltage	Load power (in watts)
4	2	8	16
2	3-1/3	6-2/3	22-2/9
1	5	5	25
1/2	6-2/3	3-1/3	22-2/9
1/4	8	2	16

source resistance, the product of current and voltage, or the output power, is equal to 25 watts, the maximum possible amount; and as the load resistance is varied above and below the matching value of one ohm, the power transferred from the battery drops off accordingly.

Electronic circuits such as servo amplifiers, modulators, and antenna feeders are generally operated with matched loads. A transmitting antenna, for example, may be considered as being essentially an impedance matching device—one that matches the impedance of the feed system to that of free space, thereby effecting a maximum transfer of radiated energy. In most instances requiring matched loads, the particular load values are seldom equal to the impedances of the driving stages; and it is then necessary to employ impedance matching devices.

LOAD MATCHING WITH TRANSFORMERS

One of the most universally used impedance matching elements in low-frequency circuits is the iron-core transformer. The factor of importance which enables the matching transformer to convert load or source impedance from one value to another is the turns ratio. This property can be shown by use of two basic formulas.

$$E_p = E_s\ (N_p/N_s)$$

$$I_p = I_s\ (N_s/N_p)$$

where E_p is the voltage across the primary winding,
E_s is the voltage across the secondary winding,
N_p is the number of turns in the primary,
N_s is the number of turns in the secondary,
I_p is the primary current, and
I_s is the secondary current.

Since Z_p (the impedance between the primary terminals) is equal to E_p/I_p, and Z_s (the secondary impedance) is equal to E_s/I_s, the following relations can be derived by dividing the voltage formula given above by the current formula:

$$Z_p = \frac{E_p}{I_p} = \frac{E_s\ (N_p/N_s)}{I_s\ (N_s/N_p)}$$

$$Z_p = Z_s \left(\frac{N_p}{N_s}\right)^2$$

The final equation is valid for iron-core transformers with unity coupling, that is, with all the magnetic flux lines linking all the turns of both windings. It states that the impedance at the input, or primary terminals, is equal to the secondary impedance multiplied by the square of the turns ratio.

To illustrate the use of the impedance formula in a typical matching problem, assume that it is required to couple a vacuum-tube servo amplifier to a resistive load of 100 ohms. Assume further that the amplifier is designed to work into a load of 10,000 ohms. The problem is then one of selecting a matching transformer with a turns ratio such that 10,000 ohms is present between the primary terminals when the secondary winding is attached to the 100-ohm load. Substituting these values in the impedance equation:

$$Z_p = Z_s\ (N_p/N_s)^2$$

$$10{,}000 = 100\ (N_p/N_s)^2$$

$$\frac{(N_p)^2}{(N_s)^2} = \frac{10{,}000}{100}$$

$$\frac{N_p}{N_s} = \frac{10}{1}$$

Thus, a transformer with a primary-to-secondary turns ratio of 10:1 provides the desired impedance match and insures maximum transfer of power from the amplifier to the given load. It can be seen from the equation, that if the resistive load had been greater than 10,000 ohms, the turns ratio of the matching transformer would then be of the "step-up" type.

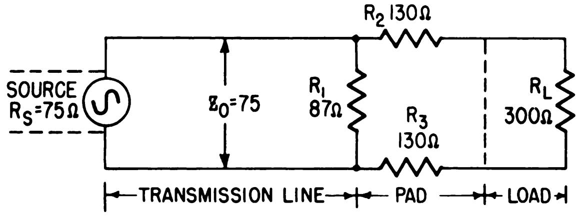


Figure 4-21.—Matching network for terminating a transmission line.

RESISTANCE PADS AND OTHER MATCHING DEVICES

Another example of impedance matching is given in figure 4-21. A transmission line with a characteristic impedance (Z_o) of 75 ohms is attached to a 75-ohm source and to a 300-ohm load resistance. To obtain maximum transfer of energy from the source, it is necessary that all elements of the system be matched. The source impedance (R_s) is matched by the input impedance of the line, which is equal to 75 ohms provided the line is terminated in 75 ohms. The correct termination value is achieved by means of the resistance pad composed of R_1, R_2, and R_3. With the values shown, these resistors, when combined with the 300-ohm load, produce a resultant resistance of very nearly 75 ohms. The line is then terminated in such a way that the input impedance matches the internal impedance of the generator. It also operates in the nonresonant condition and hence is practically free from standing waves, which are present when the terminating resistance is not equal to the characteristic impedance.

Quarter-wave and half-wave sections of transmission line, which are often used as matching stubs, operate in accordance with the principles discussed in *Basic Electronics*, NavPers 10087, chapter 10. Another typical impedance matching circuit, the cathode follower, is also treated in chapter 5 of the same text. Since both these types of devices are standard equipment in missile applications, it is desirable that the trainee study carefully the chapters referenced for additional information on impedance conversion.

In many cases it is undesirable to match the impedance of the load to the driving stage, a typical example being the vacuum-tube voltage amplifier. The purpose for which this type of circuit is used is to produce maximum increase in signal voltage without regard to output power. Hence, the grid, or input circuit, contains high impedance compared with that of the preceding stage so that very little input current is drawn and most of the source voltage appears between the grid and cathode of the voltage amplifier. This condition corresponds to the values indicated in table 4-1, which shows that in general, as the load impedance increases, the voltage developed across it increases, while the load current decreases. The voltage-amplifier plate circuit also requires a mismatch. In typical examples, the plate load resistor is made as large as possible with respect to the dynamic plate resistance of the tube, thereby providing maximum signal voltage across the load.

Limiter Circuits

The term limiting, when applied to electronic circuits, refers to the removal of some portion of an input wave. Circuits designed for this purpose are called limiters or clippers and belong to the general class of wave shaping devices. Limiters are used for converting input sine waves to rectangular pulses, for eliminating either positive or negative tips from peaked waves, and for squaring off irregular voltage swings. They are employed in many frequency-modulation receivers preceding the discriminator stages to remove noise and other amplitude variations from the i-f signals. In missile control systems, limiters serve principally as protective devices, which prevent wing-control voltages from exceeding safe levels, thereby minimizing overshooting and overcontrol when the missile is maneuvering.

DIODE LIMITERS

Basic limiter circuits are designed around diode tubes that function as switches operated by the applied signals. The limiting action

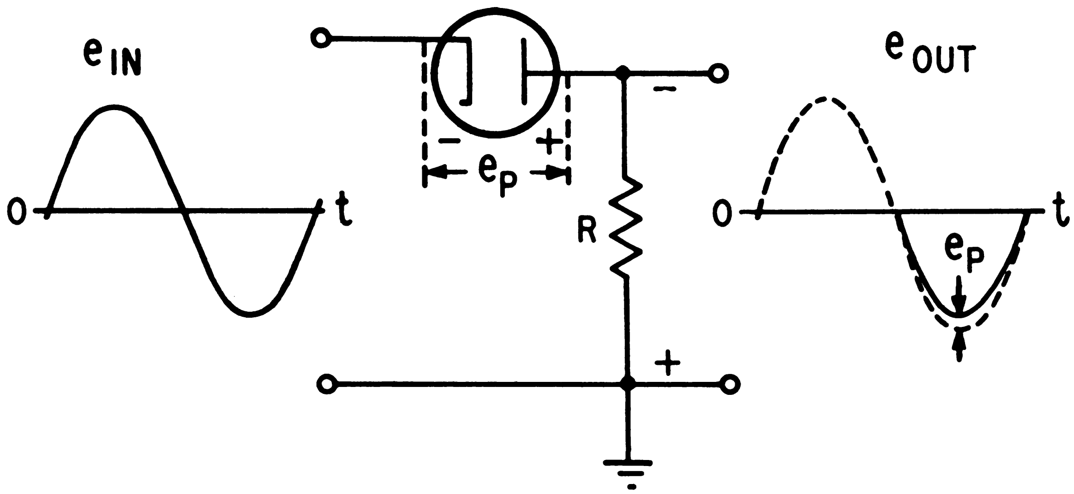


Figure 4-22.—Series diode used to limit positive signals.

results from driving the diode into conduction during certain portions of the input wave and permitting it to remain nonconducting during others. In the conducting condition, the diode is a low-resistance element with a plate-to-cathode resistance in order of 500 phms; when not conducting, it resembles an open circuit. Basic diode limiters include both series and parallel circuit arrangements. The operation of either type is based on the fact that the diode conducts only when the input voltage drives the plate positive with respect to the cathode.

Series -Diode Limiting

Series limiters of the type shown in figure 4-22 are used to clip positive halves of applied sine waves. The diode, functioning as a series switch, has an internal resistance when conducting that is small compared with resistance R. During positive halves of the input cycle, the diode switch is open and no current flows through the resistor. During negative half-cycles, the cathode of the tube is negative with respect to the plate, the tube conducts, closes the switch, and permits an output voltage to be developed across R. The output wave follows the input during conduction and is approximately equal to it, neglecting the small drop across the tube.

The series limiter (fig. 4-22) can be made to limit the negative swing of the input wave provided the diode connections are reversed. When connected in this way, the diode switch is closed during positive half-cycles only. During negative swings, the switch is effectively open and no output is developed.

Parallel-Diode Limiting

An alternative method of limiting with diodes is shown in figure 4-23. The tube is connected between the output terminals, or in parallel with the load, which in this case must be a large impedance. Since the cathode is held at ground potential, the diode conducts only during positive half-cycles of the input. During these times, the current flows principally through the diode and the series resistor, R, which is large compared with the internal tube resistance. Hence, essentially all the input voltage is dropped across R, and the output potential is then the low voltage drop (e_p) across the tube. During negative input swings, the diode does not conduct, the voltage drop across R is small, and the greater part of the applied voltage is developed across the large load impedance.

With the diode connections reversed, the parallel limiter (fig. 4-23) limits or clips negative half-cycles. In this case, the diode conducts with negative inputs and the voltage drop

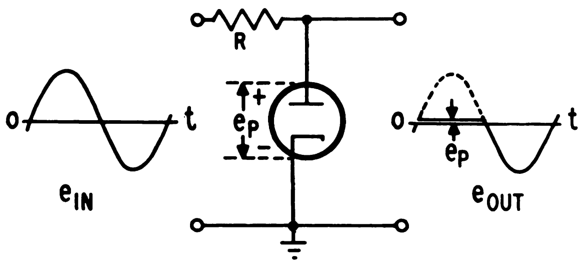


Figure 4-23.—Parallel-diode limiter.

occurs mainly across the series resistance. During positive half-cycles, the diode appears as an open switch and the output is then maximum. In either type of connection, the output wave can be considered as being limited to ground potential as a result of the switching action of the diode.

Biasing the Limiter

An input voltage can be limited to any desired voltage level, positive or negative, by holding the proper diode element at that value by means of a battery or a biasing resistor. A typical example of the biased limiter is illustrated in figure 4-24.

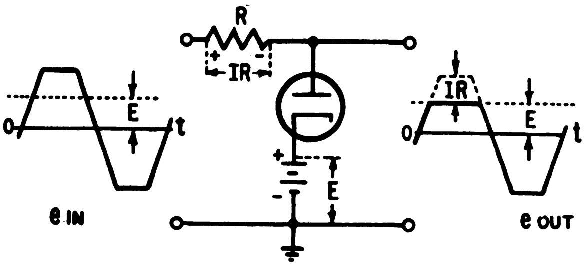


Figure 4-24.—Parallel-diode limiting above ground.

The cathode of the parallel diode is positive with respect to the plate by the value of E when no signal is applied. As long as the input voltage remains less than the battery voltage, the diode acts as an open switch and the output equals the input voltage. As indicated by the waveform drawn in broken lines (fig. 4-24), inputs exceeding the positive bias cause the tube to conduct, thereby connecting the upper output terminal to the positive terminal of the bias battery. Hence, in this condition, the output voltage is equal to the battery potential, and the difference between the applied voltage and the bias appears as an I-R drop across R, the series resistor. Operating according to the same general principle, the biased diode can be used to limit in the negative direction by grounding the positive terminal of the bias battery and by reversing the connections of the diode.

Limiters of the type illustrated in figure 4-25 have the characteristic of passing only the extremities of the input wave to the succeeding stage. The circuit shown retains the negative peaks. The entire portion of the applied wave that is more positive than the bias

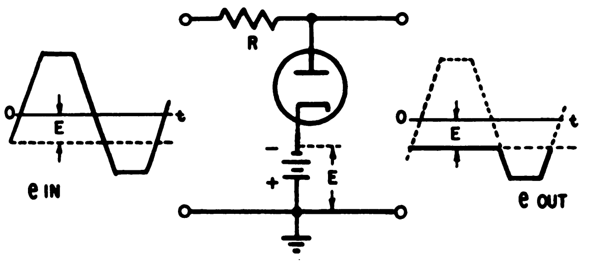


Figure 4-25.—Parallel limiter that conducts peaks only.

voltage, E, causes the diode to conduct, thereby holding the upper output terminal at the bias level. When the input swings more negative than the bias, the diode is nonconducting and the output then follows the input wave. To pass positive instead of negative peaks, both the diode and the bias-battery connections must be reversed—the battery is grounded at the negative terminal and the diode plate is attached to the ungrounded, or positive, terminal.

Double-Diode Limiters

It is possible to limit both amplitude extremes of the applied wave with two diodes connected in parallel as shown in figure 4-26. Diode V_1 conducts only when the input voltage is more positive than E_1, thus limiting the positive half-cycles. Diode V_2 conducts when the input exceeds the negative voltage, E_2, and limits the negative portion of the output to that value. Circuits of this type provide a simple method of converting sine waves to waveforms that closely approximate balanced square pulses.

Crystal-Diode Limiters

Crystai limiters contain small solid-state rectifiers instead of vacuum diodes to supply the required switching action; otherwise the circuit operation is the same as in the circuits described above. For missile applications, the crystal rectifier has several advantages when compared with the conventional diode, principally because of its physical construction. In the usual form, the crystal unit contains a small piece of silicon in contact with a tungsten wire. Rectifying action occurs since current flows readily from the wire to the silicon and poorly in the reverse direction. When a-c voltages are applied, the crystal conducts in much the same manner as the vacuum diode and hence can serve as a switching device.

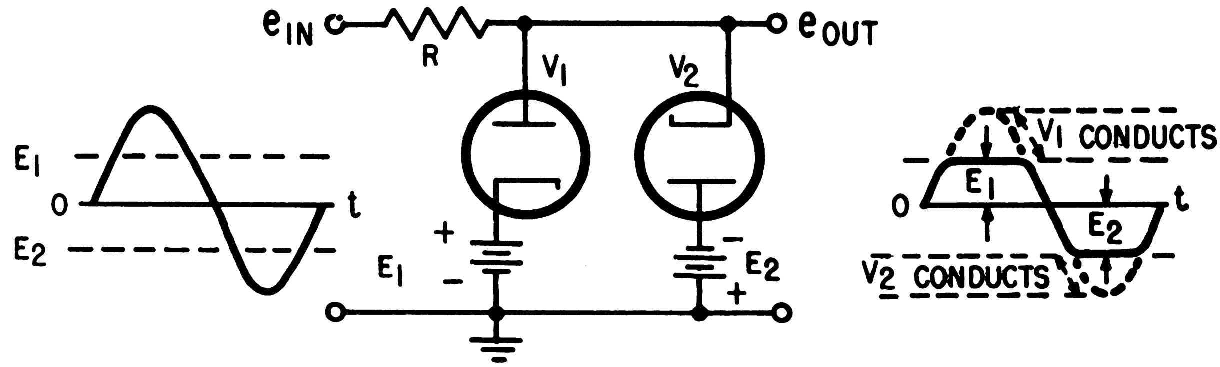


Figure 4-26.—Double-diode limiter.

The crystal limiter, like other crystal circuits, has the desirable feature of requiring no heater power and is also free from interference by power-supply energy which is sometimes coupled to the output by filament-to-cathode leakage in vacuum tubes.

LIMITING WITH AMPLIFIERS

Grid Limiting

The grid circuit of a triode, tetrode, or pentode can be employed as a limiter in the same way as the plate-cathode circuit of the conventional diode. In the case of the triode, for example, the grid-to-cathode resistance of the tube is very high as long as the grid is negative with respect to the cathode, but drops to a value in the order of 1,000 ohms when the grid is driven positive and grid current flows. Hence, if a resistor of one megohm or greater is placed in series with the grid, the operation of the input circuit is similar to that of the series-diode limiter.

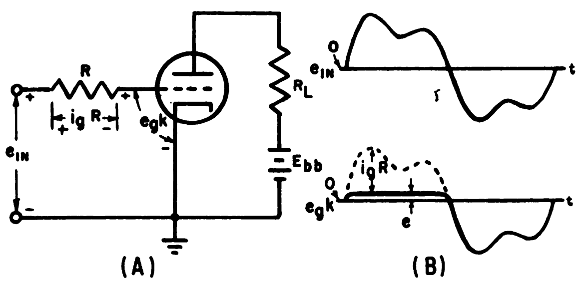


Figure 4-27.—Unbiased grid limiter.

The grid limiter shown in figure 4-27 operates at zero bias as long as no input signals are applied. With positive inputs, the grid draws current which flows through resistor R and develops a voltage drop of the proper polarity to oppose the positive applied voltage. The sum of the voltage drops across R and across the grid-to-cathode resistance of the tube must equal the total applied signal; and the larger the series resistance, the nearer the voltage on the grid is limited to the level of the cathode potential. The voltage appearing across the series resistor may be considered as an automatic bias developed during the part of the input cycle that causes grid current to flow.

A triode limiter used for clipping positive peaks and employing cathode bias is shown in figure 4-28. With no input applied, the grid is held at ground potential and thus is negative with respect to the cathode, which is at a positive voltage resulting from plate current flowing through R_k. As shown in (B), any positive input voltage that exceeds the bias potential causes grid current to flow. The resulting limiting action is then similar to that of the circuit in figure 4-27. As indicated by the grid-cathode waveform (fig. 4-28), the effect of the series resistor is to prevent the grid from swinging to levels higher than the cathode potential.

Saturation Limiting

If the input signals to be limited are derived from a low-impedance, high-power source, the plate circuit of a triode tube can be made to provide clipping action by the process called saturation limiting. The saturation limiter circuit contains no series grid resistor but has a large plate-load resistance (R_L) and a comparatively low value of plate-supply voltage (E_{bb}). The process of saturation limiting can

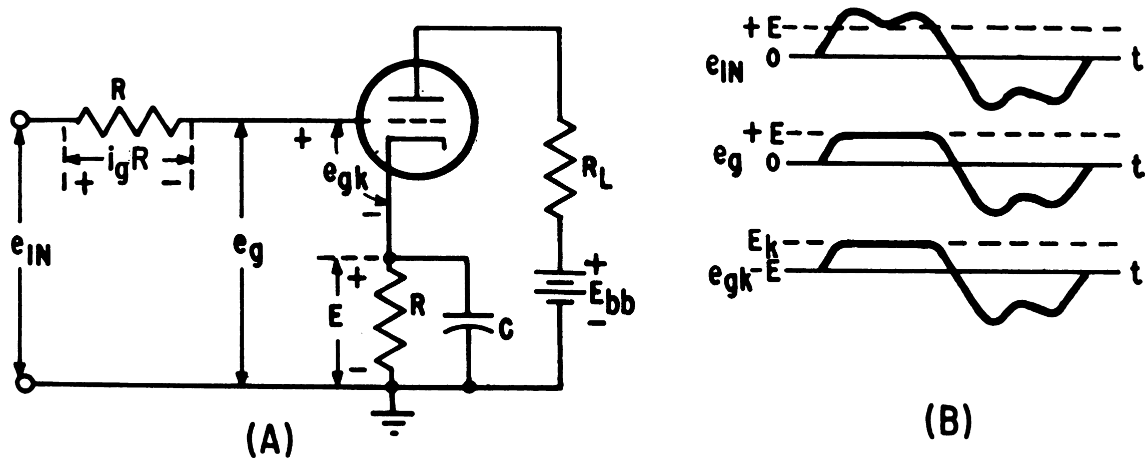


Figure 4-28.—Grid limiter with automatic cathode bias.

be illustrated by means of a load line diagram constructed on the characteristic curves of the tube. (The construction of the load line and its uses in analysis are discussed in *Basic Electronics*, chapter 6.)

The input wave applied to the triode limiter is shown in (B) of figure 4-29. The amplitude of the grid signal is great enough to cause plate-current saturation on positive swings although insufficient to drive the tube to cutoff on negative half-cycles. The resulting plate-current variation is shown in (C). The waveform in (D) indicates that when maximum plate current is flowing, minimum voltage is present between plate and cathode and an output voltage variation is developed in which the negative peak is clipped. With input voltages less than those causing limiting of the plate current, the grid exercises normal control and the remaining parts of the applied signal are reproduced without change in shape.

The output wave of the saturation limiter is similar to that of the grid limiter since the negative portion only is flattened. While producing outputs of greater amplitude, the saturation limiter has the disadvantage compared with the grid clipper of requiring considerably more driving power from the preceding stage.

Cutoff Limiting

When the grid of a vacuum tube is driven highly negative, plate current ceases to flow and remains at zero as long as the grid potential exceeds the cutoff value. With zero plate current, no voltage is dropped across the plate load and the plate is maintained at a constant voltage equal to the full value of the d-c supply. Tubes operating on this basis are called cutoff limiters and are used to develop output waves in which the positive peaks are clipped.

In the case of the triode, cutoff voltage is determined by the plate-supply voltage (E_{bb}) and the amplification factor (μ), or

$$E_{co} = \frac{E_{bb}}{\mu}$$

where E_{co} is the negative potential between grid and cathode required to prevent plate-current flow.

The cutoff potential of a typical tube, together with the i_p- e_p characteristic curves can be used to illustrate the process of cutoff limiting (fig. 4-30). The grid is normally biased to negative 5 volts by the potential across R_k. The amplification factor and the plate supply are such that the cutoff potential is negative 7 volts. As shown in (C), the maximum amplitude of the input voltage is positive 4 volts. Thus, the grid swings in a positive direction from minus 5 to minus 1 and in a negative direction between minus 5 and minus 9 volts. During the time that the grid voltage remains below minus 7 volts, the plate current is zero and the plate voltage is held at the constant level of E_{bb}, as indicated in (D) and (E) of the figure.

A combination of grid and cutoff limiting is employed by the circuit shown in figure 4-31 to produce square waves at the output. The amplitude of the applied signal must be sufficiently high to hold the grid in excess of cutoff for the greater part of the negative swing.

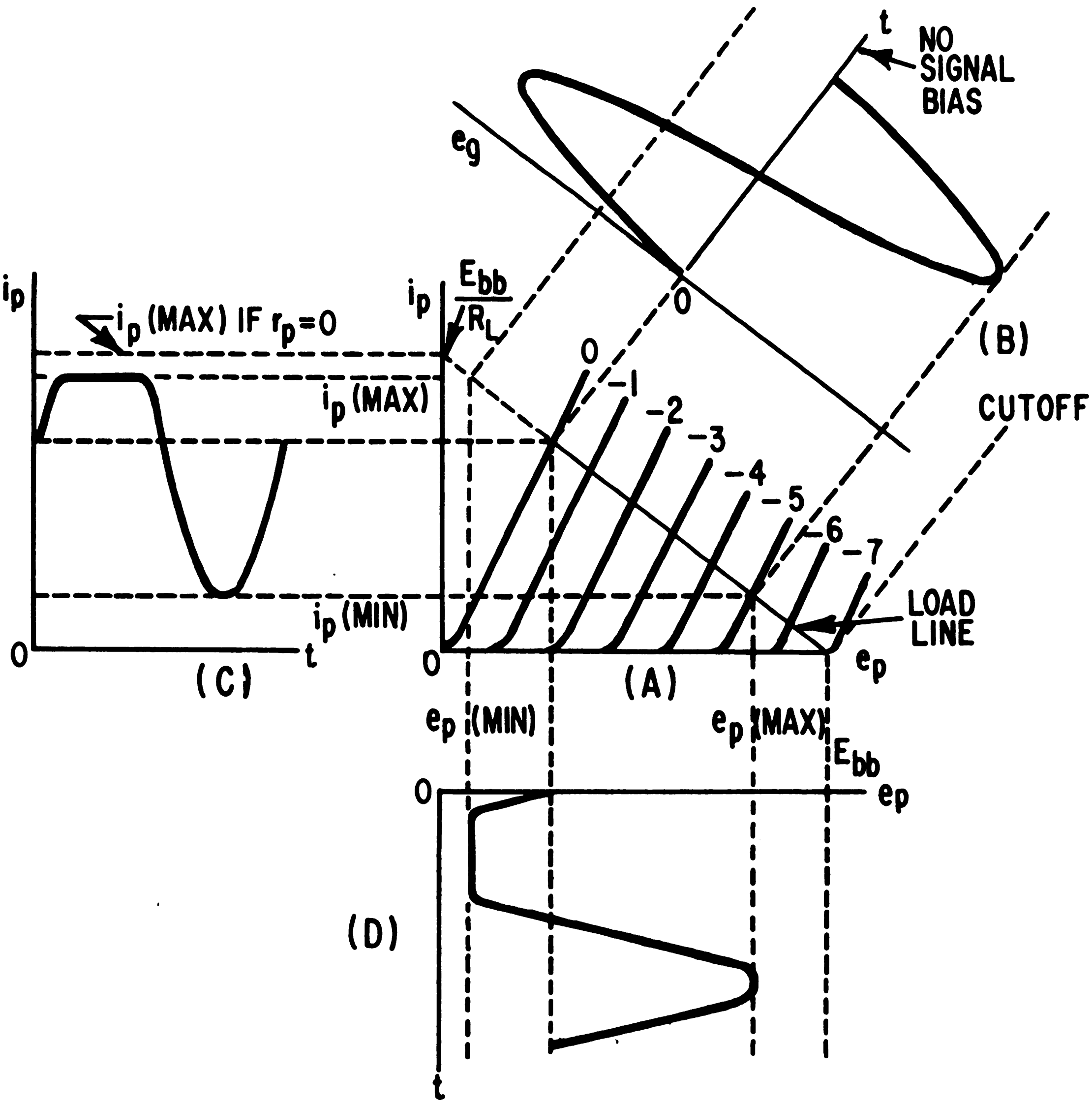


Figure 4-29.—Tube characteristics (i_p vs. e_p) illustrating saturation limiting.

During positive half-cycles, the grid voltage is limited to approximately zero by the voltage developed across the series resistor R, which is in the order of one megohm.

LIMITER APPLICATIONS IN MISSILES

In most cases, missile control systems contain circuits that restrict and limit the amplitudes of error signals to safe maximum values. This is necessary to prevent excessive control action, which might cause accelerations capable of damaging the airframe or wing structures. Typical examples of missile limiter circuits are shown in figures 4-32 and 4-33.

Two triodes operating as cutoff limiters are included in the circuit in figure 4-32. A sinusoidal input signal is developed across R_1 and fed to the grid of V_1, a cathode follower. The output of the first stage is applied to a grounded-grid amplifier, V_2, the output of which is coupled to the following stage through C_1. Under no-signal conditions, the cathode bias developed on the cathodes of the two limiter tubes is 10 volts. The characteristic cutoff potential for this type of tube is 15 volts.

Assume that an a-c signal of 20 volts, peak-to-peak value, is applied to the grid of V (fig. 4-32), causing it cut off when the

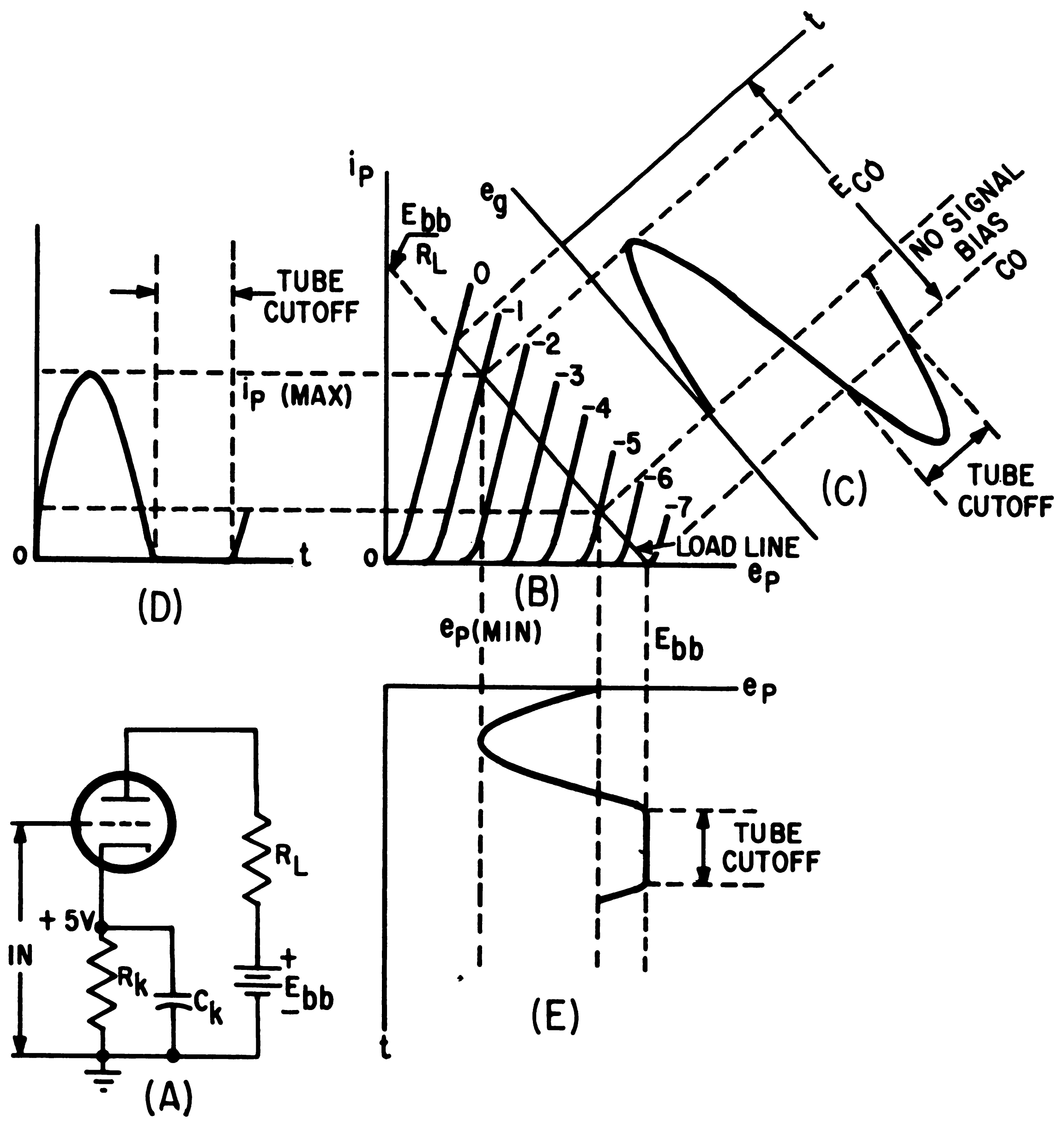


Figure 4-30.—Squaring the top of the plate-voltage wave by cutoff limiting.

negative-going part of the waveform reaches minus 5 volts. As a result, the output waveform takes the shape indicated at the cathode of V_1 in the drawing. Note that the positive-going peak is 10 volts, while the negative-going peak is limited to the 5-volt level.

The positive half of the input wave causes V_2 (fig. 4-32) to decrease in conduction until the cathode potential reaches 15 volts (cutoff potential) and cuts off the plate conduction. This condition exists until the positive input r•turns to 5 volts, when the tube resumes normal conduction. The output is then limited on both positive and negative peaks as indicated by the waveform representing plate voltage on tube V_2. Since the circuit has unity voltage gain, the output varies between plus 5 and minus 5 volts. It should be noted that any input signal with a peak-to-peak amplitude of less than 10 volts is not limited by the circuit.

Figure 4-33 shows a double-diode circuit used for limiting both extremes of an input

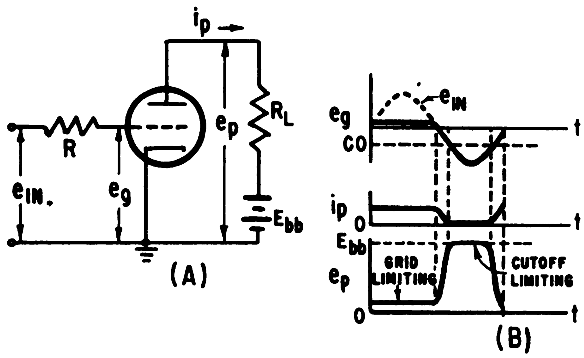


Figure 4-31.—Formation of a square wave by grid and cutoff limiting.

signal to the desired level. Under no-signal conditions, the voltage divider (composed of R_1, R_2, and R_3) establishes positive d-c potentials of 8 and 4 volts at points A and B, respectively.

Assume that the peak-to-peak amplitude of the input exceeds 8 volts. During the positive-going portion, that part of the wave in excess of 4 volts is limited by the voltage drop across R_5, which results from conduction in the plate circuit of V_1. Note that the waveform marked "V_1 plate" indicates that the reference level of the input has been moved from zero to positive 2 volts. The cathode of V_2 is at a 4-volt potential and the plate is at ground; thus any signal swinging negative in excess of minus 4 volts causes V_2 to draw current, and the excess signal is dropped across R_5 in the same manner as the positive signal is limited.

The output of the circuit (fig. 4-33) is coupled through C_2, which blocks the d-c component so that the reference level is shifted back to ground. The output has peak-to-peak maximum values of 8 volts, and signals less than this amplitude pass through the circuit with no clipping action.

Clamping Circuits

A clamping circuit shifts the reference level of a waveform by holding one of the amplitude extremes at a desired voltage. Clamping tubes are often used to reinsert the d-c components blocked when the signals are coupled through interstage transformers or coupling capacitors. In this application, the clamping tube is called a d-c restorer.

Most clampers are of the continuous type, which differs from synchronized, or keyed, circuits. Continuous clampers include diode and grid types and may be either positive or negative circuits, depending upon which amplitude peak is clamped. Synchronized clampers are controlled by keying pulses, which turn the action of the circuit on at certain times and remove it at others.

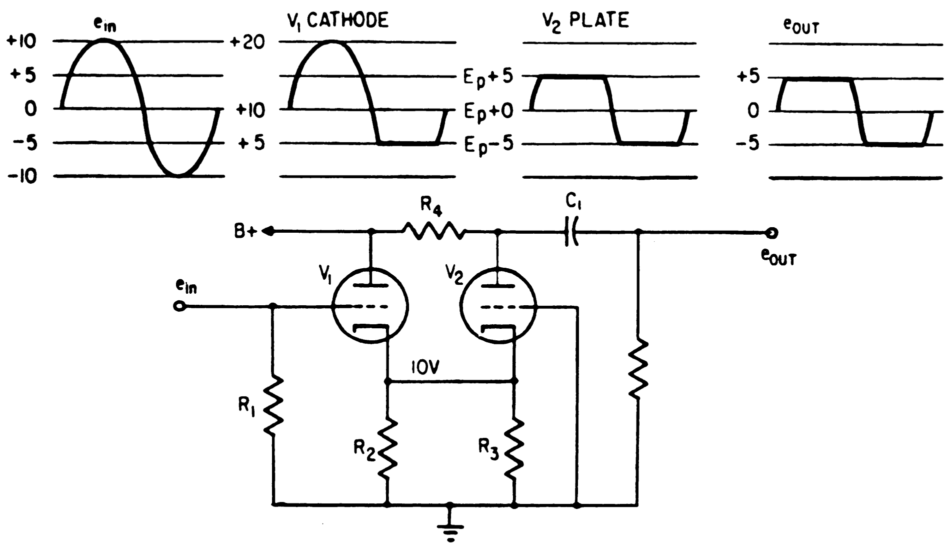


Figure 4-32.—Wing-signal limiter circuit and typical waveforms.

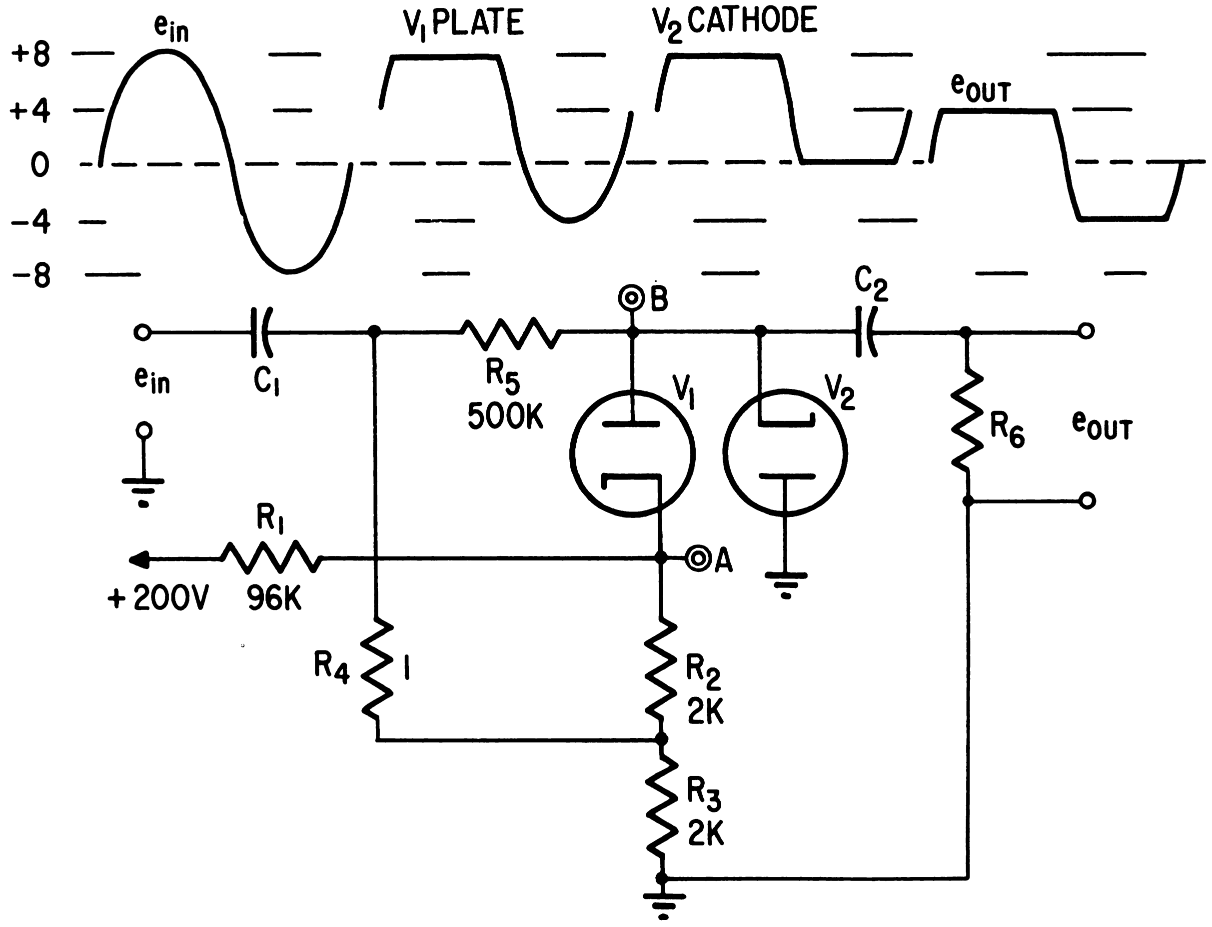


Figure 4-33.—Wing-signal limiter employing diodes.

DIODE CLAMPERS

The basic process of clamping can be understood by studying the simple diode circuit shown in figure 4-34. The waveforms below indicate the types of output with and without clamping. In the absence of the diode, the average potential of the output wave must be at ground, as shown in the left drawing. When the diode is placed in the circuit, it prevents the upper output terminal from swinging negative with respect to ground with the result that the entire voltage swing is in the positive direction. For this reason, the circuit is called a positive clamper.

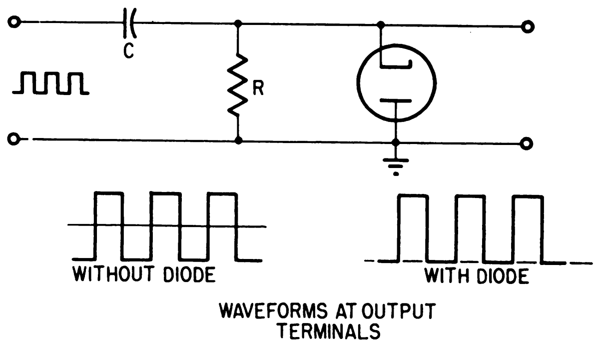


Figure 4-34.—Basic clamping circuit.

Negative Clamping

With negative clamping, the entire voltage swing is in the negative direction. The details of circuit action in this process are shown in figures 4-35 and 4-36. The former drawing gives an equivalent circuit for each half of the applied wave, a 50-volt, square pulse. Figure 4-36 shows the various values of resistor and capacitor voltages during the initial and final stages of operation.

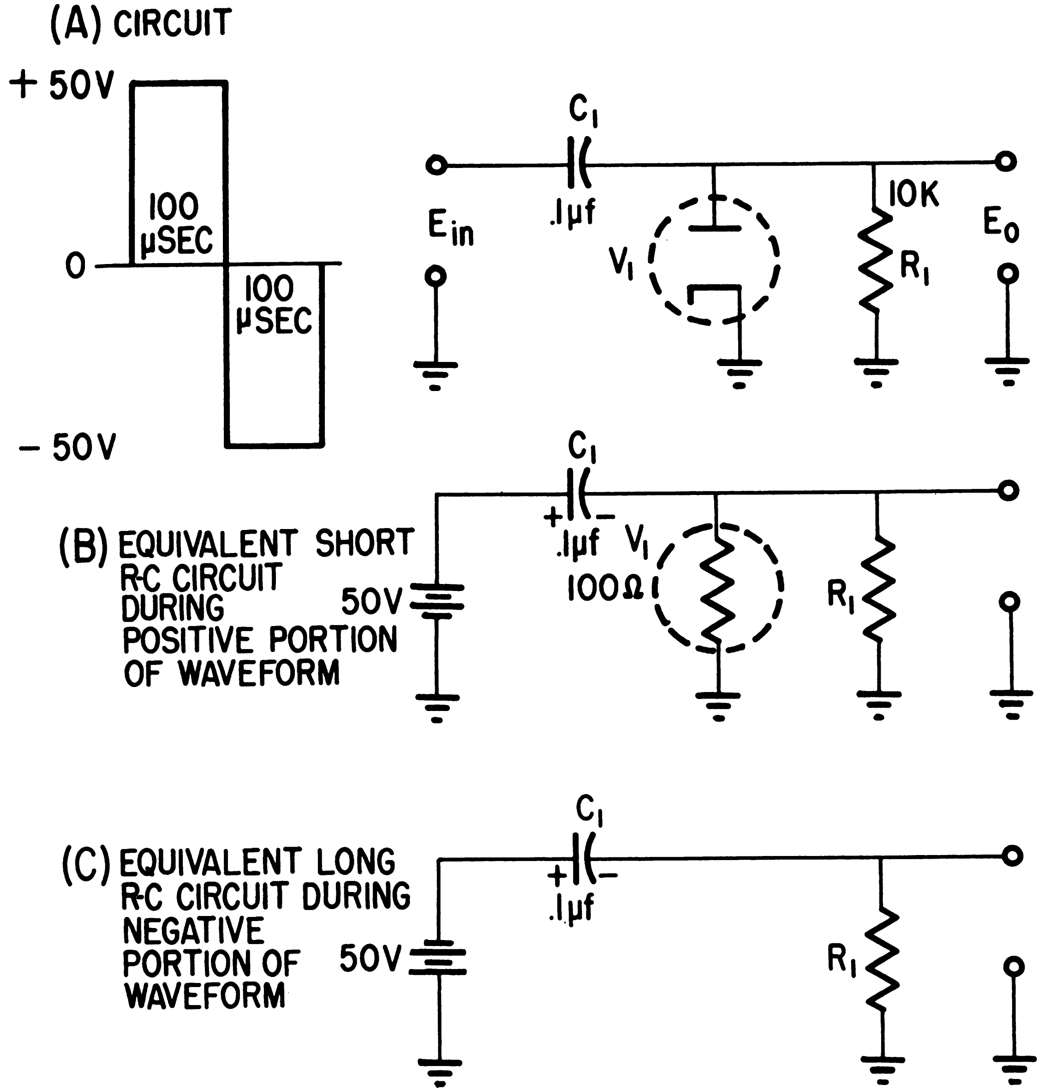


Figure 4-35.—Negative clamper with equivalent circuits.

Assume that capacitor C_1 (fig. 4-35) is fully discharged prior to application of the input. During the positive half of the first cycle, V_1 conducts since the plate becomes positive with respect to the cathode. The full applied voltage is developed across the resistor as shown in (C). The low internal resistance of the tube in conjunction with the capacitor forms a short R-C combination; and during the first half-cycle, C_1 charges to almost the full applied potential while the resistor voltage decreases from maximum to a level of about 1 volt.

During the negative half-cycle, the plate of V_1 (fig. 4-35) becomes negative with respect to the cathode so that the tube cannot conduct. A total change of voltage (100 volts) occurs effectively across R_1 so that the resistor voltage swings to minus 99 volts. The capacitor then begins to discharge, but the change in voltage is comparatively slow since the action takes place in a long R-C circuit with the tube in a nonconducting state. The capacitor voltage drops by about 1/10 the effective voltage; and at the end of the discharge period, the voltage across the resistor has become minus 89.1, while E_c reaches positive 39.1 volts.

At the beginning of the next half-cycle of input, the full 100-volt change is again developed across the resistor (fig. 4-36 (C)) causing the voltage to rise to positive 10.9 volts.

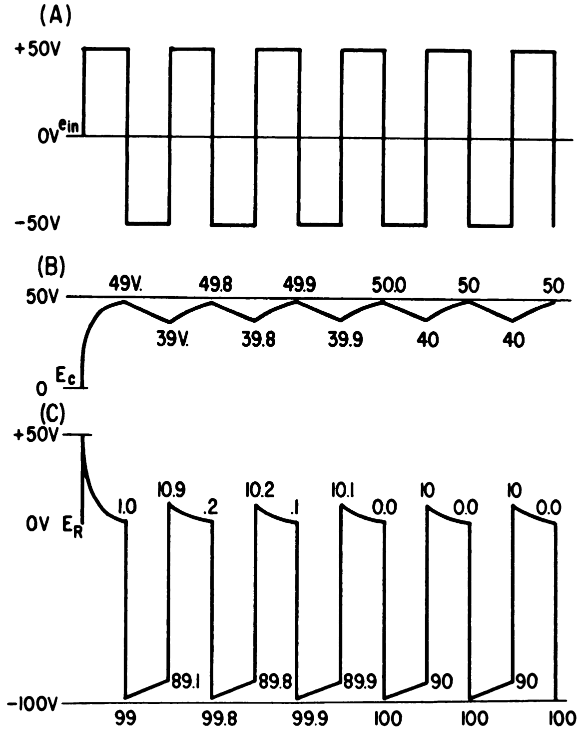


Figure 4-36.—Waveforms illustrating initial and subsequent action of negative clamping circuit.

Capacitor C_1 charges to about 99 percent of the voltage effectively applied and rises to 49.8 volts. As the capacitor is charging to this value, the voltage across the resistor is falling to the value shown in (C), or 0.2 volts.

As indicated in figure 4-36, during succeeding half-cycles of input, the voltage across C_1 approaches the final, or steady-state, condition in which it swings between plus 40 and plus 50 volts. The resistor voltage varies in accordance, changing between minus 90 and minus 100 during negative input swings and between plus 10 and zero volts during positive half-cycles.

The overall action of the negative clamper consists in holding the output voltage very nearly at zero during positive swings. The component values shown in this example are chosen deliberately so as to avoid clamping the positive peaks closely to ground potential in order to illustrate the fundamental action of the R-C combination. If the R-C time constant were made longer, improved clamping would result and the output waveform would then be less distorted.

Positive clamping could be obtained with the circuit shown in figure 4-35 by reversing the diode connections so that the plate is grounded and the cathode is attached to the upper output terminal. In this case, the output wave consists of positive swings only.

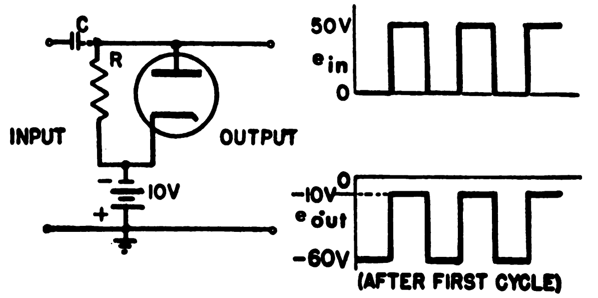


Figure 4-37.—Clamping circuit for establishing a reference level of minus 10 volts.

Clamping Above or Below Ground

All the clampers described above hold one of the output peaks at ground potential and restrict voltage swings to one polarity. In many cases, it is necessary to clamp signals to voltages other than zero, and this can be done by applying a d-c bias equal to the desired reference to one of the tube elements. An example is the negative clamper shown in figure 4-37 which establishes a minus 10-volt reference level. As indicated by the waveforms, the input is shifted so that the peaks are clamped to the cathode potential.

Any other level, either positive or negative, might be established by the negative clamper by biasing the cathode to the desired value. Positive clamping results if the diode connections are reversed. In this case, the plate of the tube is attached to the bias supply and all output voltage swings are in the positive direction.

GRID CLAMPING

Clamping action can be accomplished in the grid circuit of a triode or a pentode since under proper conditions of input, the control grid functions like the plate of a diode. Thus, the grid circuit shown in figure 4-38 functions as a negative clamper in a manner similar to the diode circuits previously illustrated.

Any tendence of the grid (fig. 4-38) to swing positive causes grid current to flow through the low-resistance, cathode-to-grid path and to charge the capacitor to the applied signal voltage. During negative swings of the input, the

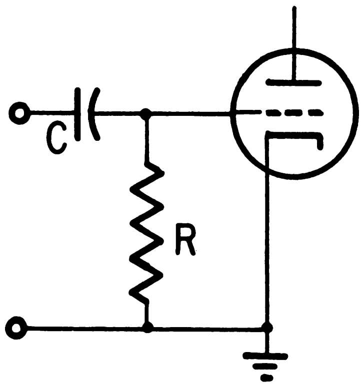


Figure 4-38.—Grid clamping circuit.

discharge path is through the high resistance, R, so that the capacitor retains a large percentage of the charge. If the time constant of the R-C combination is sufficiently long, the signal voltage applied to the grid consists of negative swings only and hence, is clamped to ground potential.

SYNCHRONIZED CLAMPING

In many radar applications, a type of clamping is required which causes a particular stage to operate for certain intervals of time and to become inoperative during others. This action occurs in the synchronized clamper shown in figure 4-39. The overall operation is such that no response is made to input signals, either positive or negative, until a synchronizing pulse is applied to the control tubes. These permit the grid of the output tube to follow the input signals and to provide amplification until it is again cut off at the end of the sync pulse.

In the absence of sync pulses, the clamping tubes, V_1 and V_2 (fig. 4-39), are both in the conducting state. Tube V_2 operates at zero bias and may be considered as equivalent to a resistor that develops a voltage drop used to bias the grid of V_1. The grids of the clamping tubes are connected and are negative with respect to the cathode of V_1, which is attached to the plate of V_2. The function of these tubes is that of a voltage divider which develops the potential controlling the grid of V_3, the output tube.

If the grid of V_3 begins to rise in response to a positive input signal, the result is to increase the bias on V_1 since the cathode of V_1 and the grid of V_3 are common. The increase in bias results in less current flow through the

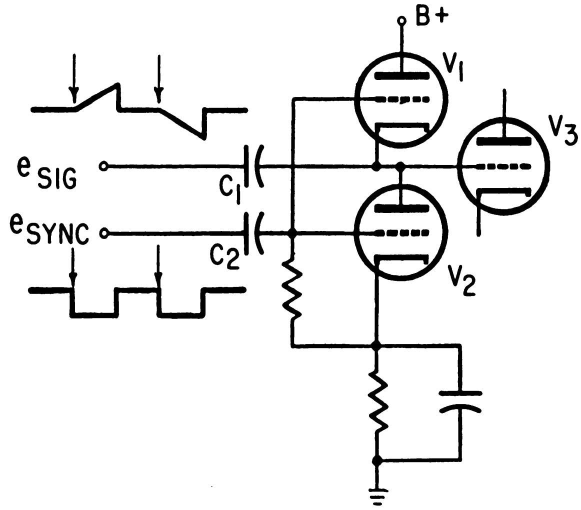


Figure 4-39.—Synchronized clamping circuit.

clamping tubes and a larger voltage drop across V_1. The cathode of V_1 thus becomes less positive and compensates for the original rise produced by the input pulse. A negative-going input pulse brings about the reverse action by decreasing the bias, thereby permitting greater conduction, decreasing the voltage across V_1, and raising the cathode potential.

Upon application of a sync pulse, both V_1 and V_2 (fig. 4-39) are driven to cutoff for the duration of the pulse and hence have no effect on the operation of V_3. Capacitor C_1 has no discharge path when the clamping tubes are not conducting and therefore it maintains a practically constant potential. The grid of V_3 can then follow the input waveform with resulting amplification. At the end of the sync-pulse period, both V_1 and V_2 again go into conduction and quickly clamp the grid of V_3 to the original reference level.

MISSILE APPLICATIONS

Typical applications of clamping circuits in missile equipment can be represented by the example in figure 4-40. Diode clamps of this type are used in many radar-controlled missiles, particularly in those containing receivers employing a number of cascaded video amplifiers for pulse amplification. In certain phases of missile flight, the pulses applied to these stages may be sufficiently large in amplitude to overdrive one or more of the amplifiers by causing grid current to flow, charging the coupling capacitors, and thereby blocking the

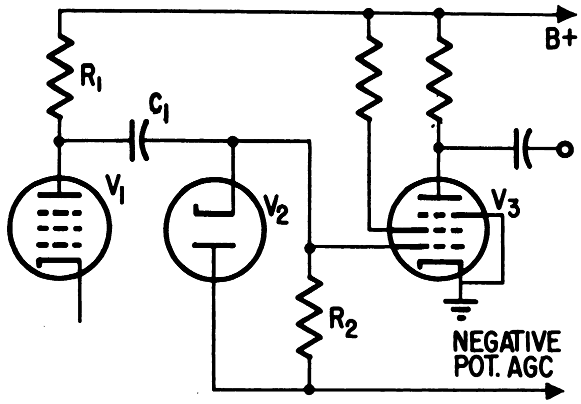


Figure 4-40.—Positive clamping below ground in video amplifier.

receiver. The clamping circuit shown in the drawing serves to prevent this effect by holding the input signals to a reference level below ground.

The output of tube V_1 consists of short-duration pulses which are coupled through C_1 to the grid of the video amplifier, V_3. The diode is in shunt with the grid resistor, R_2, and is connected as a positive clamping tube. The reference voltage in this case is the output of the automatic-gain-control (AGC) system; and it is the sole function of the clamping diode to prevent the grid of V_3 from becoming more negative than the AGC voltage.

First, assume that V_2 were not in the circuit (fig. 4-40). Then if C_1 should become charged by grid current resulting from a large positive pulse, the grid of V_3 would then be held at a negative potential by the capacitor voltage. The discharge path for the capacitor is through R_2 (in the absence of V_2), and the time constant of this R-C combination is long with respect to the duration of typical signal pulses. As a result, the charge would leak off the capacitor so slowly that the amplifier would remain cut off for a comparatively long interval, and the pulses following would not be amplified.

With V_2 in the circuit, if C_1 charges sufficiently to make the grid negative, the diode conducts and shorts out R_2, thereby attaching the grid directly to the AGC lead. Also, should the input signal drive the grid excessively negative, the same action occurs so that the grid is clamped to the AGC voltage. The AGC voltage varies in accordance with the average value of the signals applied and hence functions as a variable, rather than as a fixed, reference level except in those cases when a fixed voltage is employed for test purposes.

Counting Circuits

The missileman is most apt to find counters and related circuits in missile test equipment such as the AN/USM-26 Frequency Meter. Counting circuits receive input pulses representing units to be counted and produce output voltages proportional to the applied pulse rates. The input waveforms must be uniform in amplitude and in time duration if accurate counting is to result; and for this reason, counters are usually preceded by shaping and limiting circuits to insure the required uniformity.

Frequent application of the counter is made in frequency dividing circuits. These contain blocking oscillators or multivibrators as the final stages, which are controlled by counting circuits and develop output waves at submultiple frequencies of the input signals.

Typical counter circuits are simple combinations of diodes, resistors, and capacitors. They are classified as positive or negative, depending upon the polarity of the pulses they are designed to accept. In frequency dividers, the counting diodes develop output voltages by the process called step-by-step counting.

POSITIVE AND NEGATIVE COUNTING

Positive Counting

Positive pulses varying only in recurrence rate are applied to the positive counter shown in figure 4-41. The leading edge of the first pulse is applied immediately to the plate of V_2, since the charge on capacitor C_1 cannot change instantaneously, and the diode begins to conduct. The current flows through R_1 for the duration of the input pulse, charging the capacitor. At the end of the pulse, the drop in voltage leaves the diode side of the capacitor at a negative potential caused by the accumulated charge. Tube V_2 cannot conduct since the plate is negative with respect to the cathode. However, V_1 can conduct and it discharges C_1, removing the charge which would otherwise build up during successive pulses and eventually render the circuit insensitive to applied signals.

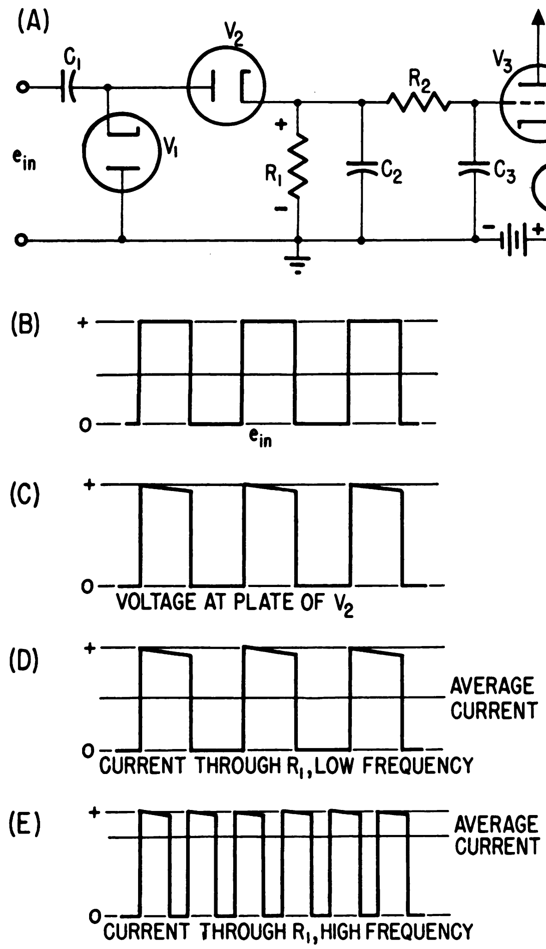


Figure 4-41.—Positive counter circuit and waveforms.

The same process is repeated with each input pulse—the capacitor charges through the long R-C containing V_2 and R_1 and discharges rapidly through V_1.

The result of the diode action (fig. 4-41) is to permit unidirectional current to flow through R_1 with an average value that rises or falls as the applied frequency increases or decreases. Hence, the I-R drop across the resistor also varies in accordance with the pulse frequency. This voltage is filtered and applied to the grid of V_3 so that it controls the current flowing in the milliammeter placed in the cathode circuit. The meter is calibrated in terms of frequency and thus indicates the rate at which pulses are applied to the counter.

Negative Counting

By reversing the connections of diodes V_1 and V_2 in figure 4-41, the circuit can be made to count negative pulses. In this case, V_2 conducts through R_1, and V_1 discharges the coupling capacitor between pulses. The output voltage developed across R_1 is then opposite in polarity to that produced by the positive counter; and if the output is applied to the same metering circuit, the milliammeter must be recalibrated to indicate increases in applied frequency with decreases in cathode current.

STEP-BY-STEP COUNTING

The step-by-step counter illustrated in (A) of figure 4-42 is similar to those discussed above except that R_1 is replaced by capacitor C_2. The latter is the output element and is large in value compared with the coupling

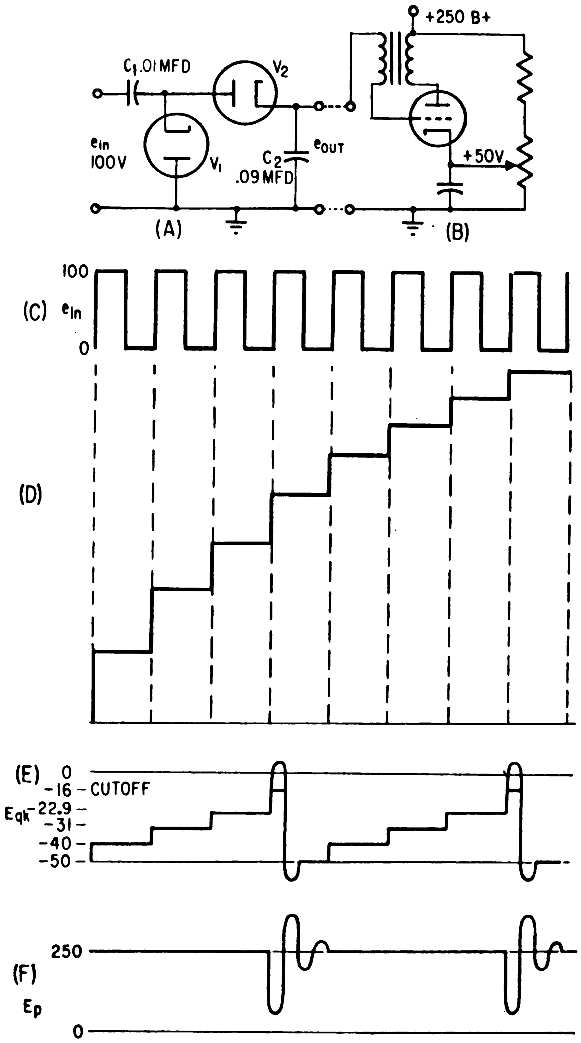


Figure 4-42.—Step-by-step frequency divider with waveforms.

capacitor, C_1. Unlike the positive counter, which develops an output voltage proportional to an average current, the step circuit charges C_2 up to a final voltage which is approached by a series of jumps, the amplitudes of which decrease exponentially until the final potential is reached. As indicated in (C) and (D) of the figure, the voltage across C_2 continues to increase until it is equal to the amplitude of the applied pulses. At this time, diode V_2 reaches a nonconducting state since the cathode is held at a positive potential equal to the voltage applied to the plate. The diode can then be made to conduct again only when C_2 is discharged by the grid circuit of the following tube.

The blocking oscillator ((B) of fig. 4-42) is triggered by the voltage on C_2. A positive potential of 50 volts applied to the cathode holds the tube at cutoff until the step-counter output raises the grid voltage to the level at which conduction can take place ((E) of fig. 4-42). When this voltage level is reached, the oscillator goes into operation and completes one normal cycle. The resulting plate-voltage waves are shown in (F) of the figure. During each oscillator cycle, the grid circuit discharges capacitor C_2, which is then recharged in steps by the diode circuit to repeat the process.

Analysis of the Frequency-Divider Circuit

The ratio of the input to output frequencies of the frequency divider (fig. 4-42) can be calculated by the following procedure. The time constant of the charging circuit in the step counter is short since only the small resistance of the diode is present. Therefore, the total applied signal voltage is developed across the two capacitors connected in series. The voltage developed by each capacitor in a series combination is in inverse ratio to the capacitances, or

$$\frac{C_1}{C_2} = \frac{E_2}{E_1}$$

where C_1 is the capacitance of the coupling capacitor,
C_2 is the capacitance of the output capacitor,
E_1 is the voltage developed by C_1, and
E_2 is the voltage developed by C_2.

In this case, the applied voltage, E_a, is equal to the sum of E_1 and E_2. Since the trigger action controlling the blocking oscillator is dependent upon E_2, this voltage is expressed in terms of C_1, C_2, and E_a, all of which are considered as known quantities. By substituting $E_a - E_2$ for E_1 in the equation above, the equation for E_2 becomes

$$E_2 = E_a \frac{C_1}{C_1 + C_2}.$$

Substituting the component values in figure 4-42 (A) into this equation gives

$$E_2 = 100 \left(\frac{0.01}{0.01 + 0.09}\right)$$
$$= 100 \left(\frac{0.01}{0.1}\right)$$
$$= 10 \text{ volts.}$$

The application of the first positive going 100 volts ((C) of fig. 4-42) charges C_1 to 90 volts and C_2 to 10 volts. As the first pulse returns to zero, C_2 is unable to discharge and the cathode end of the capacitor remains at positive 10 volts. Capacitor C_1 then applies a negative 90-volt potential to the cathode of V_1, which conducts and discharges the capacitor.

When the second positive-going pulse is applied, V_2 conducts after the pulse voltage rises past plus 10 volts since the cathode of the tube is already at this potential. Thus, the effective applied voltage is positive 90; and C_2 again increases in charge by 10 percent and gains an additional 9 volts. When the applied voltage returns to zero, the voltage remaining on C_2 is then 19 volts positive.

When the third pulse is applied, the effective voltage is 100-19, or 81 volts. C_2 then charges by an additional 8.1 volts, making a total of 27.1 volts at the end of the pulse. Successive input pulses raise the voltage of C_2 by amounts equal to 10 percent of the effectively applied voltage until the blocking oscillator is actuated.

In the oscillator circuit ((D) of fig. 4-42) the bias is set at positive 50 volts. Assume a cutoff grid voltage for this tube of negative 16 volts. This means that before the tube can go into conduction the grid must rise about 34 volts. If the output of the step counter is applied to the grid, it is seen that as the counter passes the fourth step, the output is then 34.3 volts ((E) of fig. 4-42). Application of this voltage makes the tube oscillate and the capacitor is

discharged by the grid current whereupon the cycle starts again. Since each fourth pulse results in an output pulse from the oscillator, the complete circuit acts as a four-to-one frequency divider. The frequency ratio can be changed to other desired values by changing the bias to make the tube conduct on the appropriate step. It can also be changed by changing the ratio of capacitances so that the sizes of the steps are modified.

QUIZ

1. A symmetrical square wave is composed of a fundamental and
   a. an infinite number of odd harmonics
   b. an infinite number of even harmonics
   c. an infinite number of odd and even harmonics
   d. the first three harmonics
2. The function of a limiter or clipper is to restrict a signal in
   a. amplitude without affecting the shape
   b. amplitude without affecting the frequency
   c. frequency without affecting the shape
   d. frequency without affecting the amplitude
3. In a positive series-diode limiter, the diode conducts
   a. when the input is positive
   b. when the input is negative
   c. at all times
   d. when the output is positive
4. A load absorbs maximum power from the source if the load impedance is______ the internal impedance of the source.
   a. less than
   b. greater than
   c. equal to
   d. 50%
5. In figure 4-41, C_1 charges through______ and discharges through__________.
   a. V_1 R_1 ; V_1
   b. V_2 R_1 ; V_1
   c. V_2 C_2; R_1
   d. V_2 C_2; V_1
6. In figure 4-40, the sole function of V_2 is
   a. a discharge path for C_1
   b. to bias V_3
   c. to connect the AGC to V_3
   d. to prevent V_3 grid from becoming more negative than AGC
7. A given R-C circuit may be classified as long, short, or intermediate, depending upon the_______ and the frequency applied.
   a. size of R
   b. size of S
   c. time constant
   d. number of pulses
8. The R-C differentiator is usually a
   a. short R-C
   b. long R-C
   c. intermediate R-C
   d. triangular wave
9. In missile applications, the R-C differentiator is most frequently used as a
   a. switch
   b. peaker
   c. integrator
   d. sawtooth generator
10. The integrator output with a sine-wave input is phase shifted almost____ degrees.
    a. 45
    b. 90
    c. 135
    d. 180
11. A periodic wave is a pattern of voltage or current which is
    a. repeated at regular intervals of time
    b. repeated at irregular intervals of time
    c. nonrepeating
    d. always r-f
12. A sawtooth waveform is composed of a fundamental sine wave and infinite number of
    a. both odd and even harmonics
    b. odd harmonics out of phase
    c. even harmonics in phase
    d. odd and even harmonics in phase
13. What is the instantaneous value of current in a series R-C circuit after one R-C time?
    a. 63% of maximum
    b. Maximum
    c. 37% of maximum
    d. Minimum
14. What waveshape appears across R in a series R-C circuit composed of a 10-ohm resistor and a 0.1-microfarad capacitor when the input is a balanced square wave in which the period, or time of one complete cycle, is 2,000 microseconds?
    a. Sawtooth wave
    b. Square wave
    c. Sine wave
    d. Peaked wave

15. In a positive parallel limiter, the diode
    a. conducts when the signal is positive
    b. conducts when the signal is negative
    c. acts as a switch
    d. clamps the signal in a negative direction

16. Saturation limiting with a small grid signal occurs in a tube in which the plate circuit contains a
    a. low plate load resistor and a high plate-supply voltage
    b. high plate load resistor and a high plate-supply voltage
    c. low plate load resistor and a low plate-supply voltage
    d. high plate load resistor and a low plate-supply voltage

17. In figure 4-33, if R_2 were 4K and R_1 were 94K with a 20-volt, peak-to-peak input signal, the output would be a signal that swings between positive
    a. 12 and 0
    b. 10 and a negative 4
    c. 12 and a negative 4
    d. 6 and negative 6

18. In a phase shifting R-C circuit, an increase in R will have what effect on the output waveform taken across the capacitor?
    a. Decreased phase angle between the input and output
    b. Increased frequency output
    c. Increased phase angle between the input and output
    d. Decreased frequency output

19. In a phase shifting R-L circuit, an increase in R will have what effect on the output waveform taken across the inductor?
    a. Decreased phase angle between the input and output
    b. Increased frequency output
    c. Increased phase angle between the input and output
    d. Decreased frequency output

20. The filter used in B+ supplies is a
    a. high pass
    b. low pass
    c. band pass
    d. band reject

21. A rectangular waveguide operating in the TE mode is what kind of filter?
    a. High pass
    b. Low pass
    c. Band pass
    d. Band reject

22. The load impedance is matched to the internal impedance of the source to provide
    a. maximum transfer of power
    b. high-frequency response
    c. low-frequency response
    d. minimum distortion

23. What is the turns ratio of a transformer that is used to match a tube with an R_p of 16,000 ohms and a speaker with a 10-ohm coil?
    a. 40:1
    b. 1600:1
    c. 256:1
    d. 2560:1

24. In figure 4-40, V_2 is called a
    a. positive limiter
    b. d-c restorer
    c. negative clamper
    d. negative limiter

25. A negative-diode clamper will
    a. clamp base of input to clamping potential
    b. limit positive portion of input
    c. limit negative portion of input
    d. clamp peak of input to clamping potential

26. A positive-diode clamper will
    a. clamp base of input to clamping potential
    b. clamp peak of input to clamping potential
    c. limit positive portion of input
    d. limit negative portion of input

CHAPTER 5

MICROWAVE APPLICATIONS IN MISSILE CIRCUITS

The previous chapter is concerned mainly with special electronic circuits as applied in the missile field. These consist principally of resistors, capacitors, and inductors combined in various ways, and used with conventional diode and triode vacuum tubes for producing desirable circuit effects or for providing specialized waveforms. It is the purpose of this chapter to discuss microwave applications: special tubes, some of the more complex types of circuits required in missile equipment, and the basic elements of typical missile antenna systems. The special-purpose tubes of primary importance include the magnetron and the klystron.

Magnetrons

Magnetrons are used as transmitting tubes in almost all pulse-radar systems operating at frequencies above 1,000 megacycles. In air-launched missile equipment, they are employed in most weapons with active radar homing guidance, and are encountered most frequently in missile test sets, where they serve as sources of high-powered r-f energy.

Transit time, which is one of the principal frequency-limiting factors in conventional vacuum tubes, has little effect on magnetron operation; and as a result, the latter tube has widespread use as a UHF oscillator. The magnetron has exceptional output-power capability compared with other microwave sources such as transit-time oscillators and klystrons. Some magnetrons, for example, produce pulsed peak-power levels in excess of 5 megawatts at frequencies above 30,000 megacycles while operating at better than 50 percent efficiency.

BASIC CONSTRUCTION AND OPERATION

Although many varieties of magnetrons have been developed, the most widely used, particularly in missile circuitry, is the resonant-cavity type. This tube is essentially a specialized diode in which a magnetic field is set up perpendicular to an electric field existing between the cathode and the anode, or plate. Under proper conditions, the tube functions as a self-excited oscillator and produces output energy over a range of frequencies determined largely by the number and physical dimensions of resonant cavities built into the plate structure. With regard to frequency stability, the output of the magnetron is rather poor compared with that of an ordinary low-frequency power oscillator.

Physical Construction

Figure 5-1 illustrates the physical construction of a typical eight-cavity magnetron. The basic elements include an indirectly heated cathode of cylindrical shape, an anode block, and a power take-off loop. The anode block contains a number of cavities (eight in this case) which open into the interaction space through a slot. The solid metal sections between slots are known as anode segments or anode poles. Not shown in the illustration, but essential for the operation, is a magnet mounted so that the magnetic flux lines between the poles lie parallel with the longitudinal axis of the cathode. Magnets are usually horseshoe-shaped and of the permanent type, although in some cases electromagnets are used.

Cavities and Modes

Each cavity in the anode block can be likened to a parallel resonant circuit as indicated in figure 5-2. The shape and size of the cavity determine its natural, or resonant, frequency;

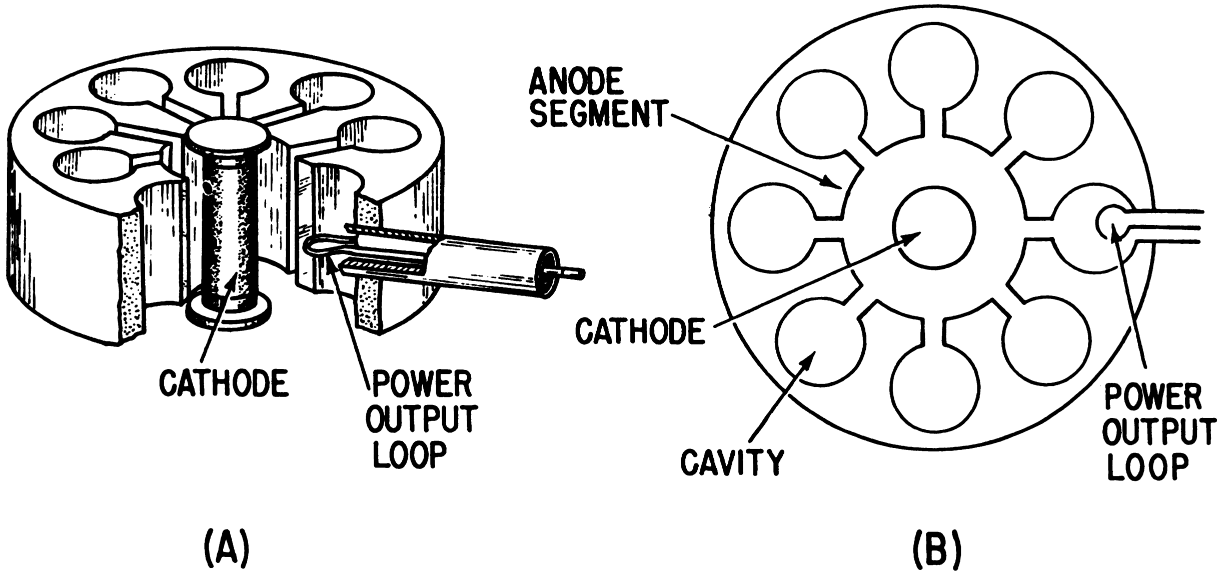


Figure 5-1.—Physical construction of a resonant cavity magnetron.

and since no two cavities of the anode block can be made exactly identical, the resonant frequencies differ by slight amounts. The number of resonant frequencies, called modes, is equal to the number of cavities present. Thus, a magnetron with eight cavities functions as a circuit containing eight resonant tanks with mutual coupling, which results from the physical construction of the anode block. In general, a magnetron with n cavities is said to have n modes of oscillation.

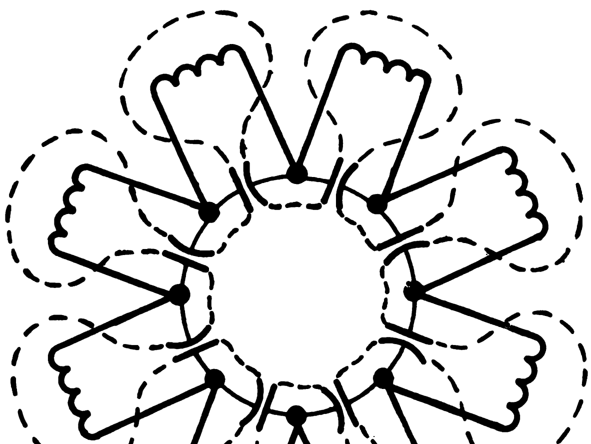


Figure 5-2.—Equivalent circuit of eight-cavity magnetron.

When two identical tuning circuits are coupled tightly, the combination resonates not at the common frequency but at two other frequencies. Similarly, the eight-cavity magnetron is capable of operation at eight different frequencies, or modes. The most desirable mode occurs when the phase difference between any two adjacent anode segments is 180°, or pi radians. This condition is usually referred to as the pi mode or dominant mode. In modes other than the dominant, the phase difference between adjacent anode segments is some value other than 180°, such as 45°, 90°, or 135°. Sustained oscillation under these conditions requires greater electron velocity than is required in pi-mode operation and consequently higher anode voltages must be applied. As a result of the comparatively low plate voltage, the operation of the magnetron in the dominant mode is more stable and efficient and the tube is easier to excite into strong oscillation.

Ring Strapping

A method commonly used to separate the pi mode from the other modes is known as strapping. In this process, two connecting rings are used in the manner shown in figure 5-3. One ring connects all the even numbered anode segments while the other ring connects all the odd numbered segments, with the rings making contact at the points indicated in the drawing. The interring capacitance acts as

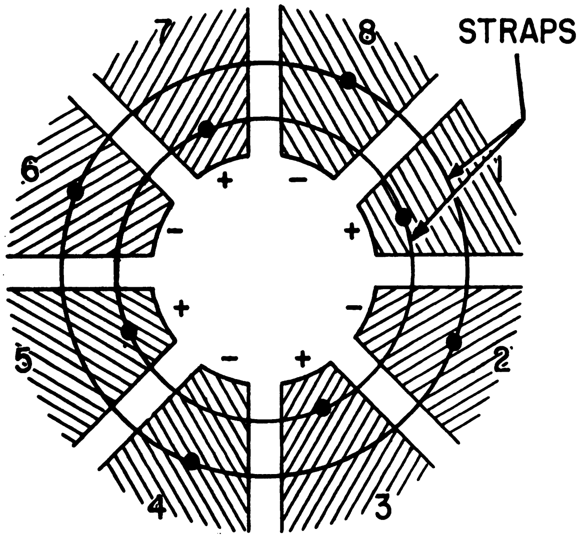


Figure 5-3.—Ring strapping.

a capacitive load, which tends to lower the frequency produced in the pi mode. The rings, on the other hand, act as an effective inductance shunt, which tends to raise the other mode frequencies. The overall action insures more stable operation and permits easier excitation and separation of the pi mode. This condition is indicated in the illustration by the plus and minus signs, which are interpreted to mean that adjacent segments are in 180° phase relation.

Magnetron Operation

To understand the processes upon which magnetron operation depends, it is necessary to consider first the motions of free electrons in combined electric and magnetic fields. The basic effects are illustrated in figure 5-4, which shows the paths followed by a single electron influenced by a d-c electric field and a perpendicular magnetic field under various conditions of intensity. In (A), the magnetic field is so weak as to be negligible. The strong electric field present results from applied voltage which makes the anode positive with respect to the cathode. In this case, an electron released from the heated cathode travels toward the anode along the straight-line path indicated by the arrow. The force of attraction varies directly with the potential difference between anode and cathode; and as anode voltage is increased, the velocity of the electron increases proportionately.

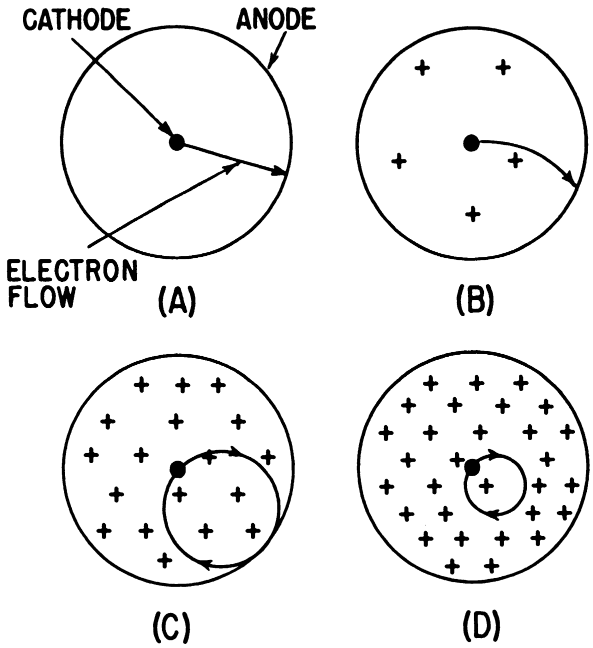


Figure 5-4.—Effects of crossed electric and magnetic fields on moving electron.

The drawings in (B), (C), and (D) of figure 5-4 show the results of increasing the magnetic field strength progressively while holding the electric field strength at a constant value. The plus symbol indicates that the magnetic flux is directed into the page, or away from the reader. The law of motion governing the electron may be stated as follows: The force exerted on an electron in a magnetic field is at right angles both to the field and to the path of the electron, and the magnitude of this force is directly proportional to the velocity of the electron and to the strength of the magnetic field.

In accordance with the law given above, the addition of a weak magnetic field causes the electron to follow a slightly curved path to the anode, as in (B) of figure 5-4. Intensifying the magnetic field causes the particle to curve sufficiently so as to just miss the anode and to return to the cathode in a circular orbit, as shown in (C). In (D), the magnetic field strength is increased to a greater value and the electron is made to travel in a circular path of much smaller diameter. Similar results can be obtained by holding the magnetic field constant and varying the electric field strength over the appropriate range.

In the operating condition, the electric field produced by the d-c anode potential applied to

the magnetron, the magnetic field of a strong permanent magnet, and the oscillating fields of the resonant cavities combine to form a composite set of forces which act upon the moving electrons. Under correct conditions of field strength, the electrons flow past the cavity openings in such a manner that energy is transferred to the circulating cavity currents and sustained oscillations are produced.

The rather involved theory of cavity excitation can be simplified if the resonant cavities are considered as being the equivalents of high-Q tank circuits with the general properties described in chapter 1 of *Basic Electronics*. There it is explained that tuning circuits of this type tend to oscillate when shock excited and remain in an oscillating condition for a considerable time following the initial shock provided no power is removed from the circuit. In the case of the magnetron, the required shock excitation is provided by the initial electrons which reach the anode when the strong d-c field is applied. This is sufficient to start the r-f oscillations within the cavities; but if power is to be taken from the oscillator, energy must be supplied to the cavities to sustain oscillation. This is accomplished by means of the moving electron beams.

Absorption of energy from the moving electrons to replace lost power occurs when the cavity electric field is in step with the approaching electrons. This condition is shown in figure 5-5. An electric field is always represented as directed from positive to negative; and with the cavity slot in the polarity shown, the electron is represented as moving through the field in the direction of the arrows or toward the negative portion of the slot. Thus it enters a decelerating field; it decreases in velocity; and gives up energy to the field. The result is to cause intensified repulsion of electrons flowing from the negative side of the cavity around the circular opening to the positive terminal, thereby giving the oscillating circuit the kick necessary to sustain it in operation at the resonant frequency.

The combined effect of the d-c field, the magnetic field, and the r-f fields of the oscillating cavities causes the electrons to bunch and to travel through the interaction space in the manner illustrated in figure 5-6. In this condition, the electrons, shown as a rotating space charge, enter the r-f fields at such times that maximum numbers of charge are decelerated and contribute energy to sustain oscillation.

The space charge, which has the appearance of spokes of a wheel, rotates at an angular velocity of two poles per cycle when operation is in the pi mode. The motion is such that the electrons travel out through the spokes and continuously supply energy to the r-f fields. After a few revolutions, electron velocity decreases in particular charges to the extent that the electrons no longer continue in orbit and are attracted to the anode. Power removal from the tube is usually accomplished by

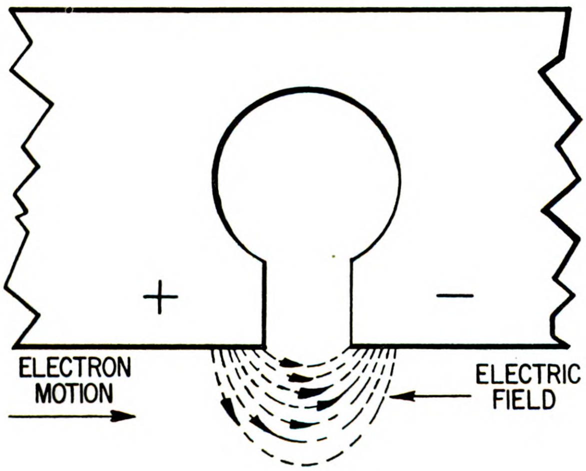


Figure 5-5.—An electron approaching the slot of a cavity at a time when it will give up energy to the a-c field.

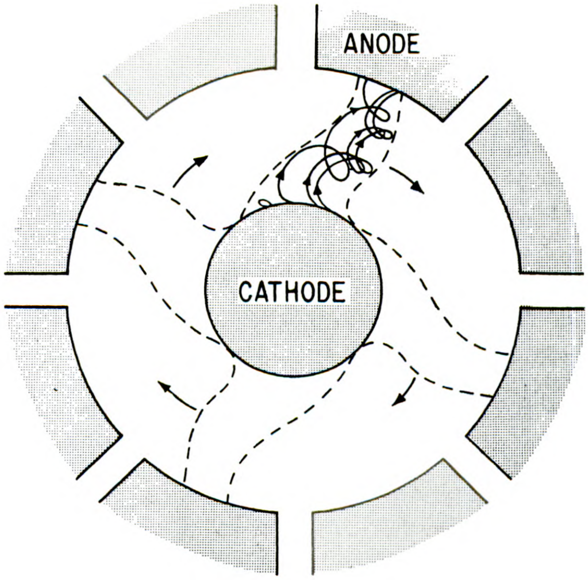


Figure 5-6.—Rotating space charge in an oscillating magnetron.

means of an inductive loop inserted in one of the cavities, as previously illustrated (fig. 5-1).

TUNING

In contrast to the magnetron, most conventional oscillators contain tuning circuits composed of external components which can be readily adjusted so that the circuit is made to resonate or oscillate at any desired frequency within a wide range. Because of the physical construction, the tuning circuits of the cavity magnetron are not nearly so available for adjustment since they form integral parts of the inner assembly. In some applications, it is necessary to frequency modulate the magnetron output. In these cases, magnetrons are employed which have provision for electrical tuning. This is accomplished by varying either the anode voltage or the magnetic field strength, thereby causing variation of the output frequency over narrow ranges. In other magnetrons, mechanical devices for adjusting the cavities are used which allow adjustment of the resonant frequency.

An inductive tuning method is shown in (A) of figure 5-7. During manufacture, nonmagnetic plugs are inserted into the tuning cavities and mechanically linked to a single diaphragm. When the diaphragm is moved by means of a screw adjustment or by a sprocket, the slugs change position in the cavities and thus change the space available for magnetic flux. As a result, the inductance value of the cavity is changed so that a corresponding change in the natural frequency of oscillation takes place. This method of tuning permits adjustment over a range of about 12 percent of the operating frequency.

Figure 5-7 (B) shows a method of tuning the magnetron by capacitance adjustment. The enlarged portion of the figure indicates a C-ring which can be moved physically in relation to the strapping rings. As stated in a preceding section, the interstrap capacitance is a factor determining the frequency of oscillation. Thus, by moving the C-ring, changes can be effected in the frequency produced by the magnetron. This method has a disadvantage in that high-power pulses may cause internal arcing in the tuning system. Capacitive tuning is usually employed in magnetrons designed for operation below 5,000 megacycles.

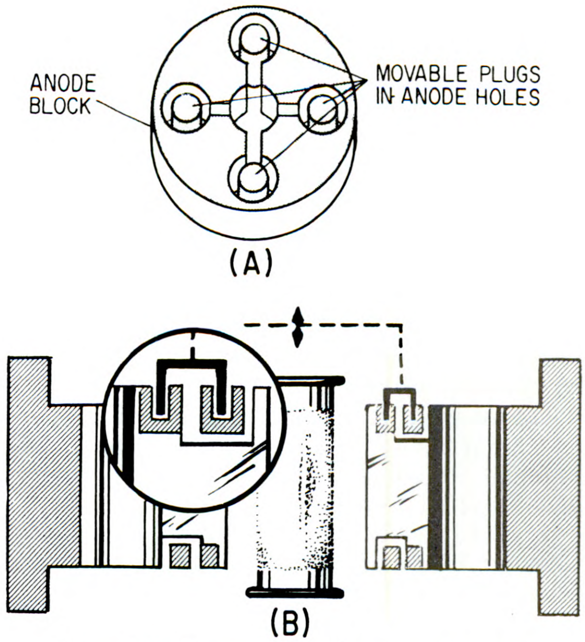


Figure 5-7.—Two methods of tuning a magnetron.

CARE AND HANDLING

Most of the magnetrons used in missile equipment contain permanent magnets, which lose appreciable amounts of field strength when subjected to mechanical shock. No magnet should be dropped, and any action which might result in even the lightest blows should be avoided. Care must be taken to keep metal tools away from the magnet or from proximity with it. An additional precaution relates to the magnetic field direction. While reversal of the permanent field should theoretically have no effect on the operating frequency or the output power, in practical operation, such reversal often causes marked changes in performance. This results from irregularities in the structure of the tube elements. Most assembled magnetrons are marked by the manufacturer to indicate the desired field direction, and care should be exercised to maintain the polarity recommended.

In many instances, it is necessary to season a new magnetron before putting it into operation. The seasoning consists of running the tube for a considerable length of time under filament power only and with no anode voltage applied. After seasoning, the high voltage is turned on and the tube is observed closely to see if arcing occurs. If so, the anode voltage is removed immediately and the magnetron is given an additional seasoning period.

TR and ATR Tubes

TR and ATR tubes are switching devices used in radar systems which make it possible to transmit and to receive microwave pulses with a single antenna. The terms TR and ATR mean "transmit-receive" and "antitransmit-receive," respectively. Both tube types are somewhat similar in construction and are often interchangeable. Also, the TR type is used alone in various missile systems as a protective device for sensitive crystal-detector and receiver circuits.

The basic TR or ATR consists of a spark gap enclosed in a gas-filled envelope. The principal action is that of ionizing the gap to cause a virtual short circuit upon application of a certain potential called the breakdown voltage. At normal atmospheric pressure and with the two electrodes set one inch apart, a breakdown voltage of approximately 30,000 volts is required to strike the arc. Once the arc is established, a much smaller voltage is needed to maintain it. This is the running voltage, which is usually about 50 volts.

When the running voltage is removed, a certain period of time is required for the gas in the tube to deionize and to restore the original condition. A typical value of the deionization time is 10 microseconds. By enclosing the spark gap in an envelope and operating it under suitable conditions of pressure, the breakdown voltage, the running voltage, and the deionization time can all be reduced and set at desirable values.

Figure 5-8 shows an application of the TR and ATR tubes as parts of a microwave transmission-reception system. The tubes serve a dual purpose. The TR prevents a transmitted pulse from entering the receiver section and burning out elements such as crystals. The ATR prevents the received pulse from losing power by isolating it from the transmitter section.

The total switching device (fig. 5-8) is called a duplexer. When the transmitter fires, sufficient voltage is applied to the TR tube to ionize it completely and to break down the spark gap. This places a short circuit across the tube a certain number of half wavelengths away from the sidewall of the waveguide. As a result, the short is reflected across the waveguide and thus prevents transmitter power from entering the receiver section. The ATR also fires during the time of transmission and similarly places a short across the waveguide. The action of both tubes permits the pulse to travel freely to the antenna with very slight power loss.

The reverse action of the duplexer during signal reception is shown in the lower drawing in figure 5-8. After the transmitted pulse has passed, both tubes deionize since the applied potentials fall below the running-voltage

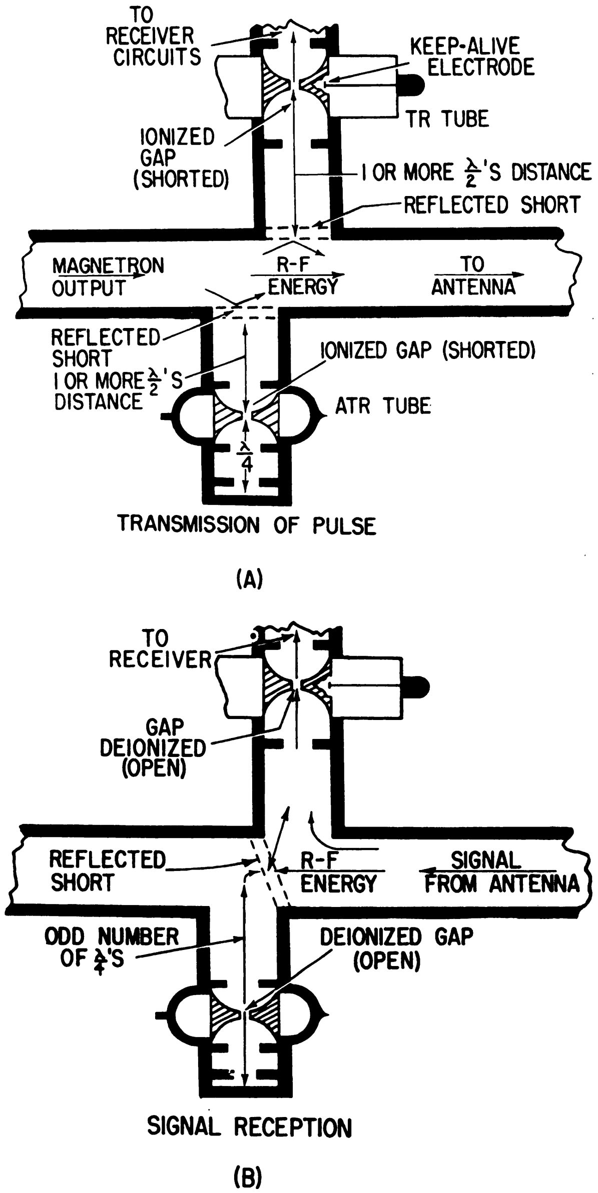


Figure 5-8.—Duplexer action in a waveguide.

values. The ATR section is constructed so that an odd number of quarter wavelengths exist between the shorted lower end and the waveguide. Also, an even number of quarter wavelengths separate the shorted end from the waveguide adjacent to the TR opening. As a result, the deionized ATR reflects an open circuit in series with the waveguide and a short circuit across it just to the left of the TR opening. Under these conditions, the incoming echo signals are guided into the TR cavity and through it to the receiver.

OPERATING CHARACTERISTICS

For efficient operation as transmit-receive devices, duplexer tubes must fulfill certain requirements. They should:

1. Dissipate very little power compared with transmitted power.
2. Maintain a properly matched impedance in the transmission line when firing.
3. Afford sufficient power attenuation to prevent receiver damage.
4. Deionize rapidly to permit reception of close-in target signals.

Keep-Alive Electrodes

Typical operation that meets these requirements is depicted graphically in figure 5-9. The curve is a voltage envelope appearing across the spark gap of a TR tube during a single cycle of ionization and deionization. The amplitude and duration of the breakdown spike must be reduced to the extent that the receiver crystal is not damaged. To insure this characteristic, many tubes are provided with a third

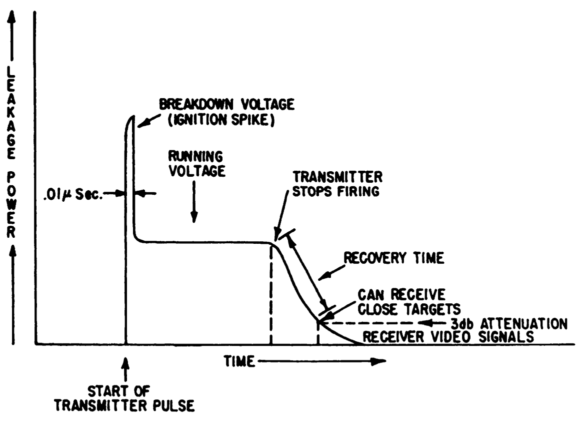


Figure 5-9.—Voltage envelope across a TR spark gap during transmitter operation.

element called a keep-alive electrode mounted near the main gap electrodes. A voltage is applied to this electrode which serves to maintain the gas at a point just below breakdown so that only a small portion of the transmitter energy is needed to complete ionization and fire the main electrodes. Because of this voltage, the gap between the keep-alive electrode and the main electrodes has a constant arc discharge, and this causes a supply of ions to be available around the gap so that full ionization occurs easily with a small transmitted pulse.

Recovery Time

An important operating characteristic of the TR tube is the recovery time. As indicated in figure 5-9, this is the interval between the end of the transmitted pulse and the time that leakage power is reduced to a level equal to a certain value of the received signal. This level is usually taken as three decibels below peak, or at the half-power point of the signal. The recovery time determines minimum range of the radar and hence is a factor affecting overall performance.

APPLICATIONS IN MISSILES

A typical TR installation in a beam-rider missile is illustrated in figure 5-10. In this case, the tube serves to protect the crystal detector from large pulses of r-f energy when the missile is near the radar transmitter of the launching aircraft. When this distance is such that the receiver circuits might be damaged, the received r-f energy ignites the tube and places a short circuit across the waveguide. At safe distances, the smaller amplitude pulses pass through the deionized TR to the crystal. To insure that the TR does fire at the specified pulse amplitude, a keep-alive electrode maintains the enclosed gas in a state of partial ionization. The tube is tunable and the cavity is adjusted to resonate at the operating frequency of the parent radar. The tuning feature also assists in reducing the effects of unwanted signals which pass through the TR tube.

In another application similar in principle to that shown in figure 5-10, the TR tube is kept ionized or fired regardless of the signal strength for a predetermined period of time after launching. The firing voltage is then removed either by a switching relay or by the

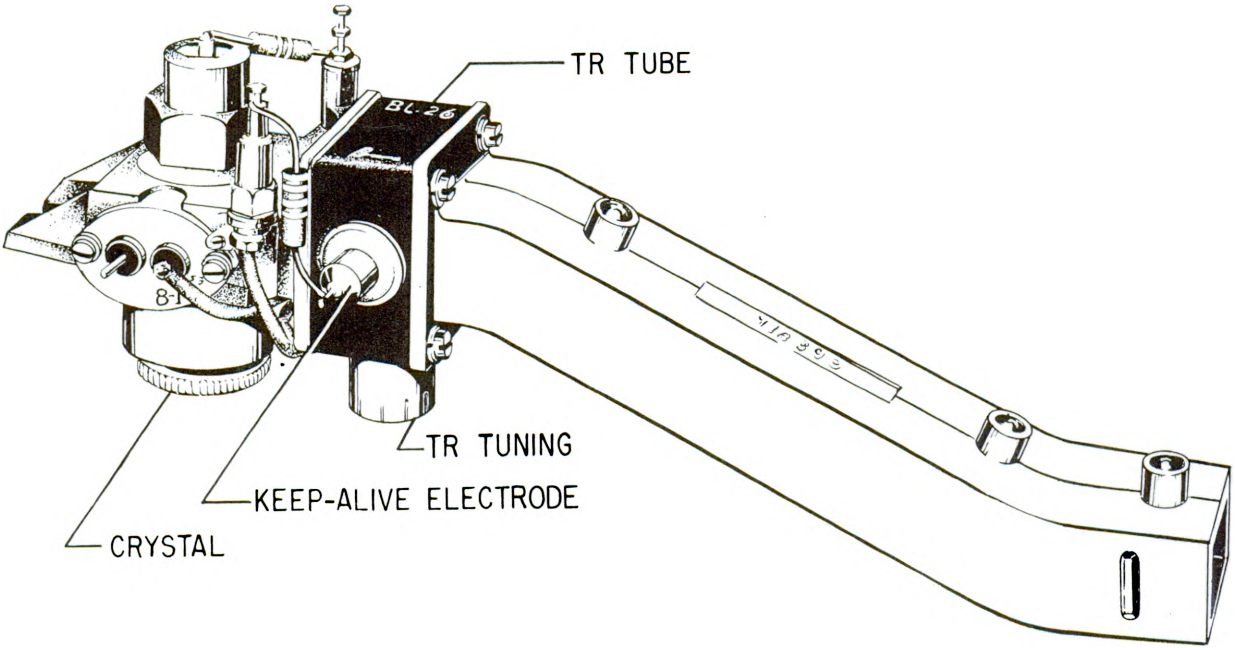


Figure 5-10.—TR tube location in a missile waveguide.

action of an R-C combination to permit passage of guidance signals to the missile receiver.

In missile equipment the TR tubes must be selected with recovery-time characteristics in accordance with the purpose of the system. Missile homing radars, for example, require tubes with very rapid recovery to allow reception as the missile closes on the target. Typical values are in the order of 2.5 microseconds. On the other hand, high-power, long-range radars may employ tubes with recovery times as long as 40 microseconds.

Tuning and Sensitivity

Most TR tubes and some ATR types have provisions for tuning by means of screw adjustments which vary the spacing between the main electrode tips. Careful tuning of the switching tubes is necessary since the cavities function as high-Q tank circuits and, as such, have narrow bandpass ranges. The tubes are tuned so that the operating frequency of the transmitter falls well within the bandpass region of the cavities in normal operation. Also, provision for tuning permits adjustment for deviations in the magnetron output frequency. Improper tuning of the switch tubes has considerable effect on system operation since it can cause a decrease in effective receiver sensitivity by passing only a small portion of the incoming signals.

Tube Life

The operating life of gas switching tubes is short compared with conventional vacuum tubes. The chief cause of failure is the loss of pressure in the enclosing envelope due to absorption of gas by the electrodes. The result of this process is usually indicated by a decrease in the current drawn by the keep-alive electrode; and readjustment of the keep-alive voltage to keep the current within recommended limits is an aid in lengthening tube life. Check points are provided in some equipments which facilitate checking electrode currents to determine the condition of the TR elements. In addition to abnormal current readings, the following symptoms indicate faulty operation:

1. Increase in receiver recovery time.
2. Decrease in receiver sensitivity.
3. Increase in the failure rate of receiver crystals.

Crystal Mixers and Detectors

Microwave crystals are used in many missile systems, particularly those based on radar guidance, for the purpose of frequency conversion. Efficient amplification is difficult to obtain at microwave frequencies; and in the missile receiver, the incoming guidance information is usually converted to a comparatively low frequency before supplying the amplification required to increase it to the levels needed by the control section. This process is accomplished in two ways. In systems containing superheterodyne-type receivers, crystal mixers are employed to produce the low intermediate frequencies. In systems such as the beam-rider, a crystal detector is included as one of the first stages of the receiver and serves to convert microwave pulses to video signals containing the guidance data.

In low-frequency circuits, ordinary vacuum tubes are suitable for use as converters and detectors; but in the microwave region, these are inadequate because of the large amounts of internal noise they generate and also because of transit-time losses.

MICROWAVE CRYSTALS

The solution to the problem of frequency conversion of microwaves is provided by the silicon crystal diode and similar crystal elements. The crystal is advantageous for this general purpose since it has low inherent noise, it introduces small conversion losses, and is of comparatively small physical size—the latter characteristic being an important advantage in missile applications. On the other hand, it has certain disadvantages when compared with vacuum tubes. It is delicate and requires careful handling. It has low-power dissipating capabilities; and it can be easily burned out by an accidental discharge of static electricity.

Construction

The physical construction of typical microwave crystals is illustrated in figure 5-11. The rectifying action, by reason of which the crystal functions as an equivalent diode, is provided at the contact between the tungsten "whisker" and the wafer of silicon. The elements are sealed in a cartridge for protection and for stability of the silicon properties. The term crystal generally refers to the entire assembly, two examples of which are shown in the drawing.

Fundamental Circuit

The basic crystal mixer circuit is shown as a schematic diagram in figure 5-12. The incoming microwave signals and the output of the local oscillator are applied in series with the crystal. Since the latter element functions as a rectifier, it provides the necessary nonlinear operation required in frequency conversion. When two signals of different frequency are introduced in a circuit of this type, the result is the production of a beat-frequency equal to the difference of the original frequencies. This becomes the intermediate-frequency signal, which contains the modulation, or signal information present in the incoming microwave reception. The tank circuit is tuned to the i-f signal, thereby presenting high impedance to it and low impedance to other frequencies. The voltage developed across the tank circuit is then coupled to the input of the first amplifier of the i-f section, which provides the required amplification.

THE BALANCED MIXER

Mixers of the type illustrated in figure 5-12 have the disadvantage of introducing large amounts of noise generated in the

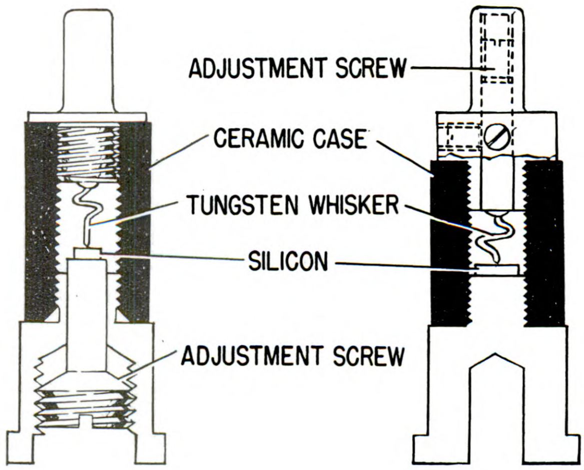


Figure 5-11.—Microwave crystal construction.

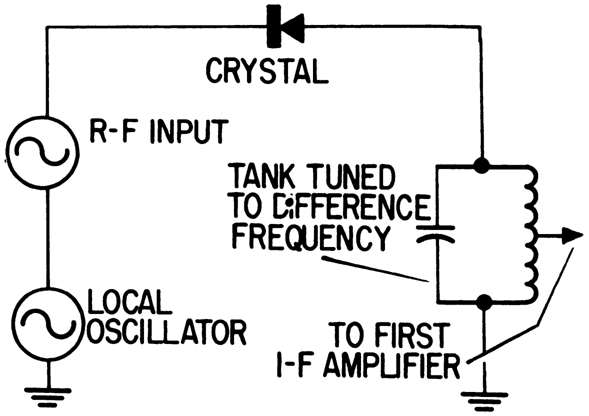


Figure 5-12.—Schematic diagram of a microwave crystal mixer.

local-oscillator circuit. It has been found that negligible noise voltage originates in stages preceding the mixer; while comparatively large quantities are produced by the oscillator, particularly when operation is above 3,000 megacycles. The local-oscillator output voltage is greater than the r-f signal voltage in the ratio of ten to one or more; and when noise energy is produced at these levels and amplified through the entire i-f section of the receiver, it can easily override and obscure the comparatively weak echo signals.

The drawings in figure 5-13 illustrate a balanced mixer circuit, typical of the type used in many air-launched missiles with active or semiactive radar guidance systems. The operation of the mixer is such that noise generated in the klystron local oscillator is eliminated from the circuit output and hence prevented from being fed into the i-f stages.

Drawing (A) of figure 5-13 indicates the major components of the balanced mixer in the manner in which they are shown in missile handbook schematics. Two crystals, CR_1 and CR_2, serve as rectifying elements and provide the nonlinear circuit operation needed for mixing. The output tank is tuned to the i-f signal produced as a difference frequency by combining the r-f input with the local oscillator output. The principal component of the circuit, shown in (B) of the figure, is a waveguide junction called a magic-T. Drawing (C) is an equivalent circuit which indicates the basic operation of the mixer. Before this can be understood, however, it is necessary to consider the properties of the magic-T junction, upon which the entire action of the circuit depends.

The magic-T belongs to the general class of waveguide elements called hybrid junctions which are composed of E-type and H-type junctions in combination. (Discussion of the fundamental principles involved in the conduction of E and H fields in waveguides is given in *Basic Electronics*, NavPers 10087, chapter 10. In relation to the circuit described here, the information concerning the TE mode in rectangular waveguides is particularly important.) Because of its physical construction, the magic-T exhibits certain basic properties, which can be understood by reference to drawing (B) of figure 5-13. These are the following:

1. Signals of the TE mode applied through arm C flow into the junction and develop voltages at arms A and B which are 180° out of phase. No signal entering the junction at arm C flows into arm D.

2. Signals applied to the junction through arm D produce outputs at arms A and B which are in phase. No output signals appear at arm C as a result of waves entering the junction at arm D.

As can be seen by the equivalent circuit in (C) of figure 5-13, the balanced mixer functions as a bridge circuit. The local oscillator signal is applied to the magic-T at arm C; and in the equivalent circuit, this corresponds to attaching the voltage across the bridge, since the effect is to produce voltages at A and B which are out of phase. The r-f signal is introduced through arm D; and in the equivalent circuit this is shown to correspond to a generator which is applied so as to produce in-phase voltages at arms A and B. The resistance arms of the bridge are made up of distributed resistances within the circuit and are not composed of ordinary lumped resistance components.

The local oscillator (fig. 5-13 (C)) permits current to flow in the crystals only during alternate halves of the oscillator cycle. Hence, this voltage functions as a switching signal that swings the crystals into and out of conduction at the local-oscillator frequency. During conduction periods, the r-f input voltage causes current flow through the crystals and also through the tuned tank circuit. Conduction in the mixer is thus determined by two signals which differ in frequency. As a result, a difference-frequency signal is developed, which can be extracted by the tuned tank and coupled to the first i-f amplifier.

During conduction through the crystals, the local-oscillator voltage produces equal voltage

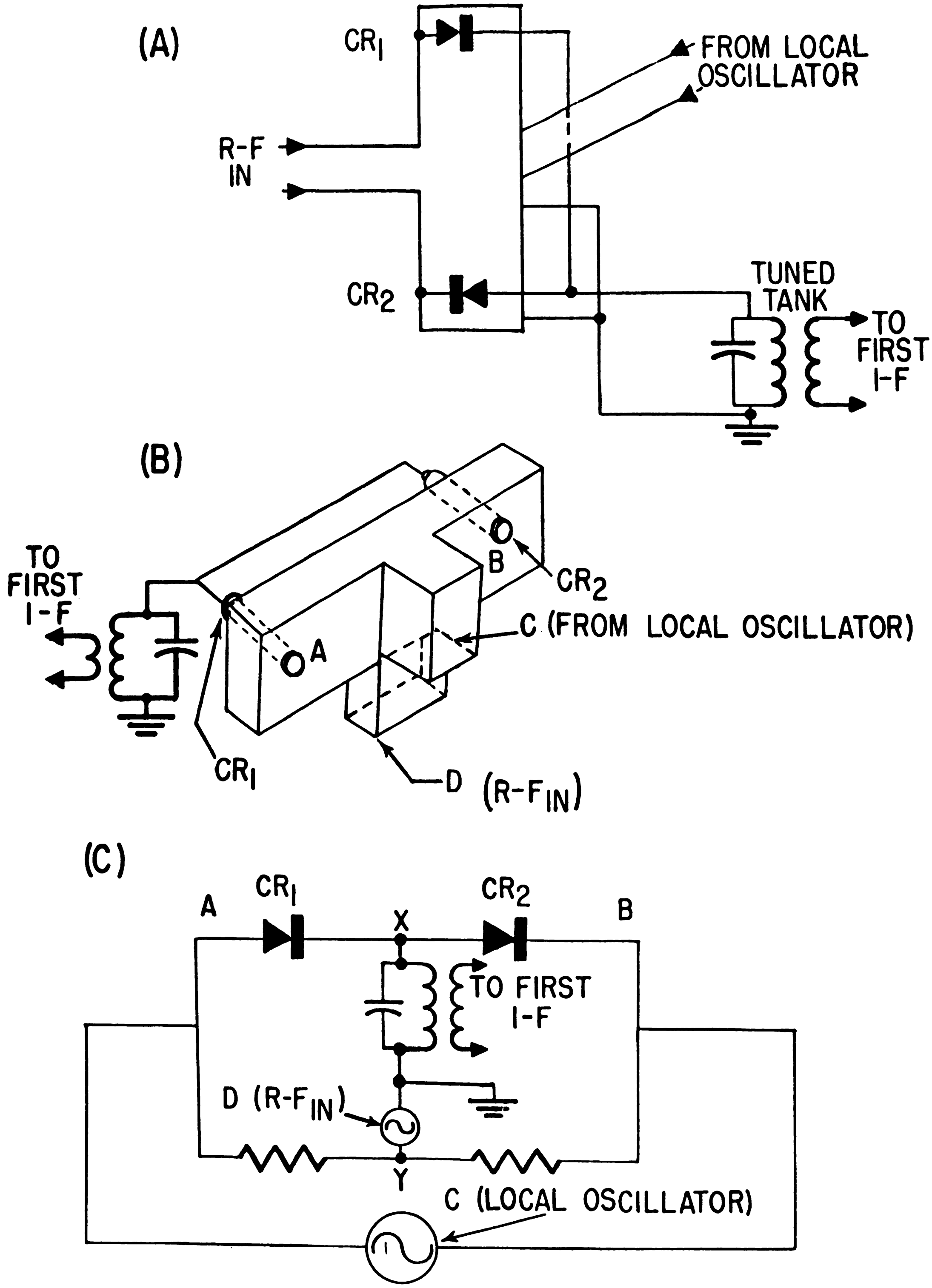


Figure 5-13.—Balanced mixer schematic, waveguide junction, and equivalent circuit.

drops across the two crystals and across the resistance arms; therefore, the bridge is balanced with respect to the oscillator signal and no output is developed by it between points x and y. Thus, the large-amplitude oscillator output as well as any noise energy it may contain are excluded from the output of the mixer.

CRYSTAL DETECTORS

In some instances it is not necessary to convert microwave signals to intermediate frequencies since the high selectivity of the superheterodyne-type receiver is not required in the system. This is the case in most beam-rider missiles. The strength of the signals received by the missile antennas is relatively high compared with signals received in other systems; and in addition, the effects of interference can be minimized by careful design of the antenna section. Typical beam-rider receivers contain crystal detectors following the receiving antenna section. The detector circuit is followed by several stages of video amplification to provide the necessary increase in beam-information signals.

A crystal diode detector is shown in figure 5-14. The waveguide operates in the TE mode and is terminated in a short circuit. The crystal is inserted in the waveguide in a probe-type mount situated one-quarter wavelength from the shorted end. The probe acts as a receiving antenna and the crystal rectifies the received microwave pulses. The inductance of the coupling lead connected to R_1 (the detector load resistor) combines with stray capacitance of the leads to form an L-C filter. The filter removes r-f voltages and permits only video pulses to appear at the grid of V_1. This tube is a cathode follower, which serves as an impedance matching device between the detector output and the first video amplifier.

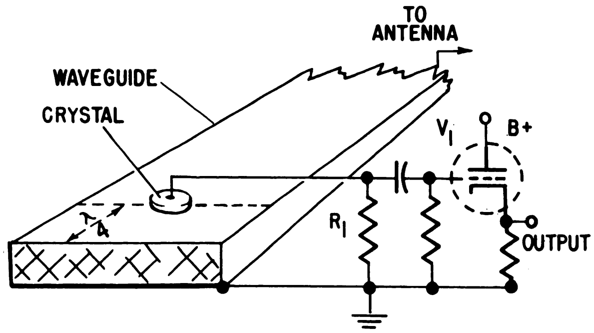


Figure 5-14.—Microwave crystal detector.

The Klystron Oscillator

Most active homing missiles employing pulse radar contain receivers of the superheterodyne type with intermediate-frequency sections which operate in the order of 30 to 60 megacycles. In these receivers, practically all the amplification given the echo signal occurs in the i-f amplifiers; and consequently, stability of the local oscillator is a highly important factor. For example, in a radar with a carrier frequency of 10,000 megacycles, a shift of as little as 0.1 percent in the local oscillator results in a change of about 10 megacycles in the i-f signal. Since the bandwidth of most receivers is less than this quantity, the result may be loss of the guidance information entirely, or at best, a considerable decrease in the gain of the receiver.

In addition to stability, a radar local oscillator must be tunable over a range of several megacycles to compensate for changes in the transmitter frequency or in the oscillator circuit elements. The power developed by the oscillator need be only a few milliwatts, however, since in most cases the output is applied in low-power crystal mixer circuits. The tube that meets these general requirements better than most other types is the reflex klystron. Hence, it is employed almost exclusively as a microwave local oscillator and is also widely used as a low-power source in microwave signal generators.

THE REFLEX KLYSTRON

Construction

The physical construction of a typical 10-centimeter reflex klystron is illustrated in the cutaway drawing in figure 5-15. The tube is tuned by means of external cavities. Note that tuning plugs are provided which can be adjusted to give coarse frequency control. By screwing the plugs into or out of the cavities, the effective sizes of the tuning elements are varied, thereby causing corresponding variations in resonant frequency. In the tube shown, there

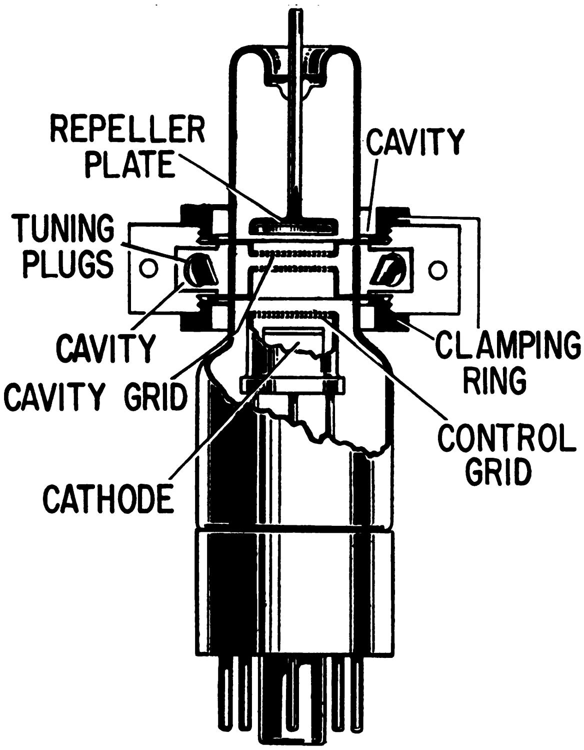


Figure 5-15.—Construction of a reflex klystron.

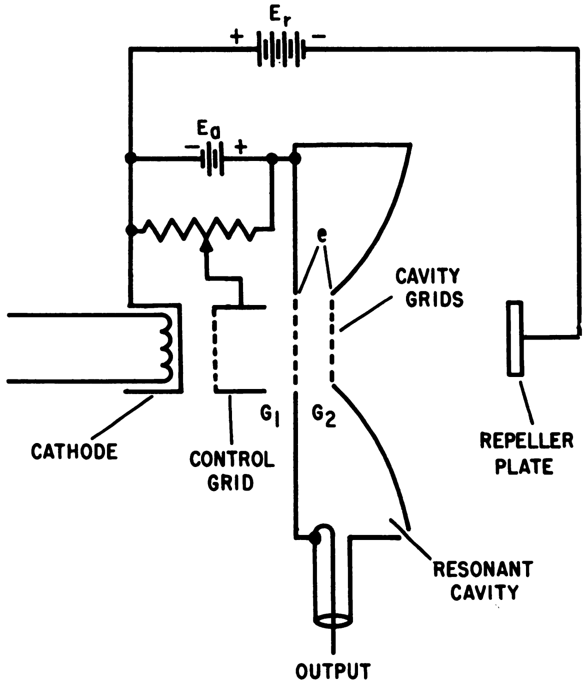


Figure 5-16.—Schematic diagram of a reflex klystron oscillator.

is no provision for evacuating the cavities and, hence, changes in temperature result in changes in cavity dimensions which, in turn, can cause changes in operating frequency. In many cases, stability is improved by the use of temperature-control elements. The term reflex refers to the basic operation of the tube in which electrons emitted from the cathode are reflected or turned back by the negative repeller plate and returned to the region near the cavity grids where bunching action occurs. This can be best described by reference to a schematic diagram with which the overall operation can be made clear.

Theory of Operation

The schematic (fig. 5-16) indicates the arrangement of the electrodes in the reflex klystron and also the voltages involved in operation. Electron emission is from an indirectly heated cathode. Free electrons are attracted by the cavity grids (usually called buncher grids), which are more positive than the cathode by the value of voltage E_a. The cavity functions as a parallel resonant circuit similar to those discussed in the section of the chapter dealing with the magnetron. The control grid, which is also called the accelerating grid, is located between the cathode and buncher grids. In polarity, it is negative with respect to the buncher grids and positive with respect to the cathode. The repeller plate, or reflector, is made negative with respect to the cathode by the value of E_r and negative with respect to the buncher grids by the sum of E_r and E_a.

Electrons emitted from the cathode (fig. 5-16) travel toward the buncher grids at a velocity determined mainly by E_a. Most pass through the control grid and the buncher grids and continue on toward the repeller plate. The region around the latter electrode contains an electric field which opposes electron motion. As a result, the electrons slow down, stop, reverse in direction, and pass back through the buncher grids.

Most of the returning electrons are collected by the buncher grid nearest the cathode, by the accelerating grid, and by the shell. Those not collected continue toward the cathode, where they are again reversed in direction by the accelerating field and sent back through the buncher grids a third time. This group of

electrons is capable of causing malfunction of the tube, and care is taken in design to insure that repeated travel through the grids is minimized.

In most oscillator circuits, some irregularity in current flow serves to initiate oscillation. This action often results from the sudden application of voltage to the tank circuit, thereby shock-exciting it into oscillation, with the subsequent action of the tube serving to strengthen and to sustain the circulating current within the tuning circuit. This general procedure is employed in the klystron. The application of voltage results in excitation of the resonant cavity; and the a-c fields present are then reinforced and sustained by the action of the electron stream.

When the cavity begins oscillating, a high-frequency voltage (designated in figure 5-16 by the symbol e) appears between the two buncher grids; and since this voltage alternates in polarity, the electric field present between the grids reverses in direction during each complete cycle. The time required for a given electron to pass through the space between the buncher grids is very small compared with the period of oscillation. Those electrons entering the grid space when e is zero encounter little or no effect from the oscillating field and pass through with no change in velocity; but those entering when the field intensity is high are either accelerated or decelerated, depending upon the direction of the field. For example, electrons entering the grid space when G_2 is maximum positive with respect to G_1 are accelerated by an amount proportional to the value of e. Those entering when e is maximum in the opposite polarity are decelerated by an equivalent amount. The accelerated electrons travel farther toward the repeller than the slower moving charges, which are turned back sooner because of lower kinetic energy. Thus, it is possible that with proper values of e, E_r, and E_a, the electrons returning to the cavity grid can be made to arrive in bunches.

Figure 5-17 shows the positions of electrons in the tube at various instants of transit time in relation to buncher-grid polarity. The zero position, taken as the baseline in the graph, is midway between the buncher grids. Electron A, which arrives when G_2 is positive, is accelerated and travels farther before being turned back than does electron B, which arrives when G_2 is zero. Electron C is decelerated since it arrives at a time when G_2 is negative, and as a result, it turns back after a shorter excursion. As a result of this action, electrons return to the grids in a stream which varies in intensity at the frequency of oscillation determined by the tuned cavity. Because of this, the klystron is called a velocity-modulated tube; and since electrons reverse in direction and travel through the buncher grids twice, it is further described by the term reflex velocity-modulated tube.

Velocity modulation of the electron stream provides the means by which energy is delivered to the resonant cavity in proper phase to sustain oscillation. When electrons are accelerated by an electric field, their kinetic energy is increased by energy supplied by the field. If, on the other hand, electrons are decelerated, they give up energy to the field, thereby increasing the field strength.

With these facts in mind, consider once more the diagram in figure 5-16. When electrons return from the repeller, the electric field set up by the voltage e again modifies their velocities. Since the electrons now travel in the opposite direction through the grid space, they are decelerated if they reach the position between the grids when G_2 is positive with respect to G_1. They are accelerated if they arrive when G_2 is negative. By proper choice of applied potentials, electron bunches can be made to enter the grid space when G_2 is maximum positive. Under this condition, energy supplied originally by the applied d-c voltages is coupled by the electron bunches to the a-c field. Sufficient energy can be transferred in this way to overcome the losses in the cavity so that sustained oscillation occurs in the circuit. In the oscillating condition, power can then be taken from the klystron by an inductance loop located inside the resonant cavity.

Power Modes of Operation

Study of figure 5-17 reveals that oscillation can be produced in the klystron in more than one way so that the tube exhibits various modes of operation. The term mode in this connection refers to a power value; and this meaning is in contrast with that of the same word when applied to magnetrons where it refers to a particular frequency value.

It is seen from figure 5-17 that it is not necessary that the electron bunches return to the center of the grid space on the first positive swing of G_2. Several possible conditions of arrival result in oscillation. Two of these

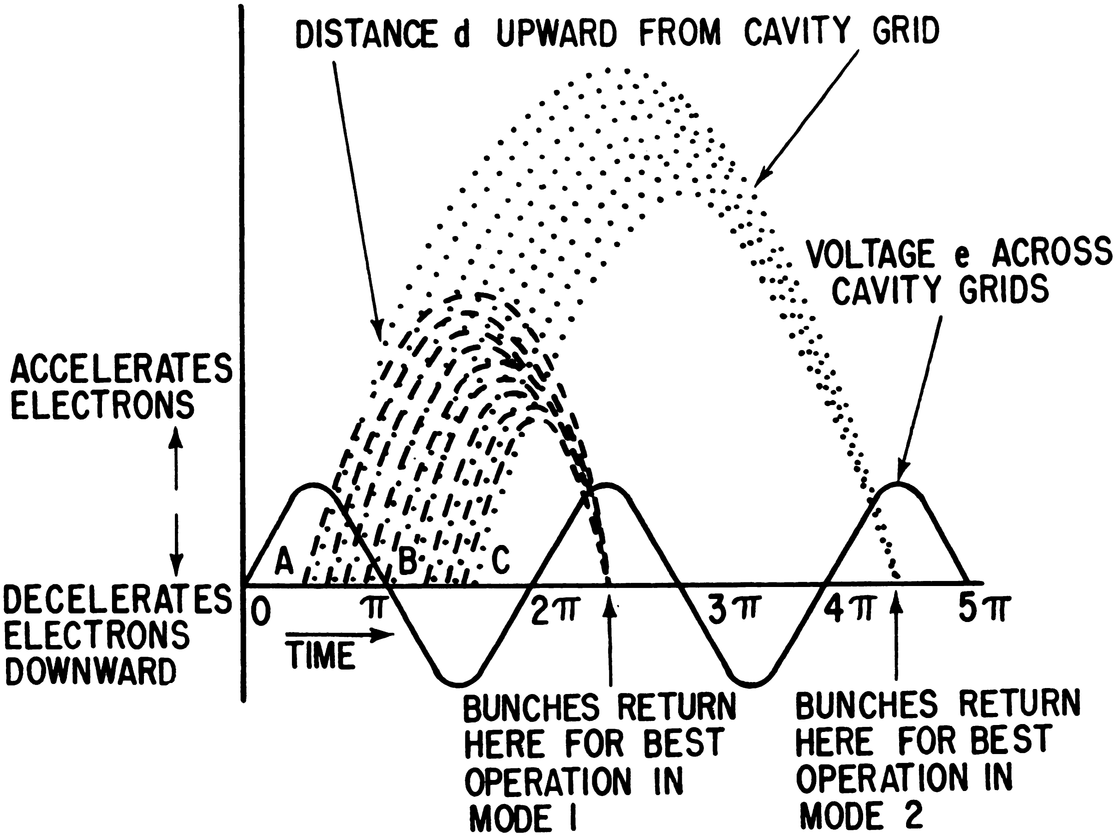


Figure 5-17.—Bunching action of the reflex klystron.

are illustrated. The dashed lines indicate bunched electrons returning on the first positive swing, while the dotted lines indicate bunched electrons returning on the second positive swing. In either case, the bunches yield energy to the a-c field and sustain oscillations in the cavity. These two conditions result from different values of repeller plate voltage, which give different values of transit time. The principal requirement is that the bunches must arrive at such times that they give up energy to the a-c field.

Three power modes of a reflex klystron are indicated in figure 5-18. Note that maximum output power in all three modes is produced when the cavity is operating at the resonant frequency. (This is in contrast with the magnetron, which develops different frequencies in different modes of operation.) In mode 1, the bunched electrons kick the cavity once each time G_2 goes positive with the result that the output is maximum. In mode 2, the bunched electrons kick the cavity on every other positive swing of G_2; while in mode 3, the cavity is kicked every third positive swing of the grid. As a consequence of the decreasing amounts of energy supplied in the higher order modes, the power output of the oscillator decreases.

It is possible in practice to obtain slightly higher output power values from modes 2 and 3 than is indicated in figure 5-18 by adjustment of the output impedance to minimize the losses within the cavity. But in general, as the mode order increases, the output power decreases. The curves also indicate that changes in reflector voltage to values above or below that corresponding to peak output power result in a shift in frequency with a corresponding decrease in output. This results from the fact that the cavity then operates off resonance. In this condition it is analogous to a triode oscillator in which the feedback is shifted in phase so that current pulses in the plate circuit do not correspond with minimum plate voltage, the result being a shift in output frequency and a lowered output power value.

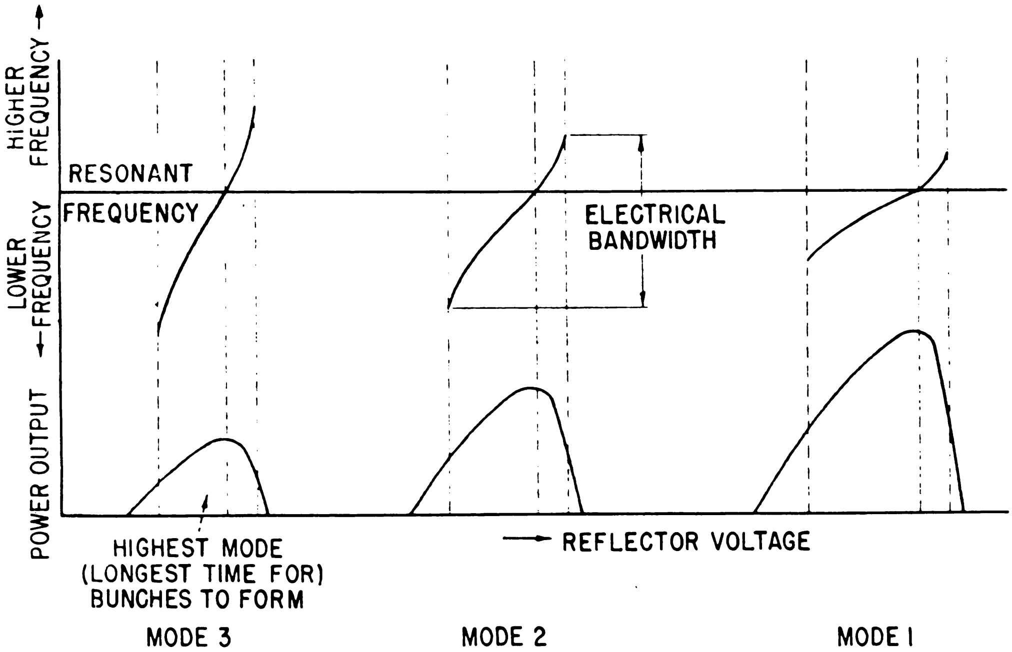


Figure 5-18.—Power output and frequency versus reflector voltage in different modes of a reflex klystron.

TUNING

The fact that the klystron frequency can be varied over a certain range is a factor of importance in radar receiver applications. The band of frequencies obtainable in each power mode by varying the reflector voltage is comparatively small. Typical values of tuning range are in the order of 50 to 60 megacycles for a klystron with a cavity resonant at 9,400 megacycles. The tuning range is called the electrical bandwidth of the mode and is defined as the group of frequencies represented on the curve as situated between the half-power points.

As shown in figure 5-18, the bandwidth varies somewhat from one mode to another and is greatest in the highest order mode. The general reason for this can be understood from the discussion of circuit Q and bandwidth given in *Basic Electronics*, NavPers 10087, chapter 1.

As previously stated, the klystron cavity is comparable to a parallel resonant circuit. When resistance is added to a circuit arrangement of this type, the effect is to decrease the Q and to increase the bandwidth. This general effect occurs in the higher klystron modes. As shown in figure 5-18, the power output in mode 3 is considerably less than in mode 1, although the tube produces the same output frequency in both. Hence, in the higher mode, operation is as though resistance had been added to the cavity, thereby increasing effectively the circuit losses, lowering the Q, and increasing the bandwidth.

In practical applications, the reflex klystron is operated in the mode most suitable for the particular circuit requirements. In equipment requiring high-power output, the tube is operated in a low-order mode; while in applications requiring variations in operating frequency, a mode of higher order is employed. The principal example of the latter type of operation in missile equipment is in automatic-frequency control (AFC), which is discussed in the following section. The klystrons used in this type of circuit are constructed with provision for coarse adjustment of frequency—usually by some means of varying the cavity size. In addition, a variable voltage applied to the reflector element provides a means for fine adjustment of output frequency.

Automatic-Frequency Control (AFC)

The term AFC refers to automatic systems used in many radio and radar microwave receivers for the purpose of maintaining correct local-oscillator frequency. These systems are necessary in equipment operating in the UHF and microwave ranges since the companion transmitters are characterized by poor frequency stability when compared with conventional low-frequency equipment. This is caused by factors which have negligible effect at lower frequencies but which are increasingly important as the operating frequency is increased. Among these factors are the following:

1. Size. Since microwave frequency-determining components are necessarily small in size, any condition which changes the shape or any of the dimensions can cause a corresponding shift in frequency. These conditions may be vibration, temperature variations, or changes in atmospheric pressure.
2. Frequency pulling. This results from load variations which are often caused by reflection from nearby objects, or from variations in the electrical or physical properties of transmission lines.
3. Voltage variations. These are often the result of poor regulation in the power source or of changes in the amplitude or frequency of the primary power.

CLASSIFICATION OF AFC SYSTEMS

AFC systems fall generally into one of two major classifications. One, the absolute-frequency system employs a method whereby the frequency of oscillation is determined by reference to a precision standard such as a high-Q cavity. This system has very limited application in the missile field and will not be discussed in this chapter. The second type, the difference-frequency system, is the more commonly used and is described in detail. In this system, the local oscillator is maintained at a frequency which is greater or less than the transmitter frequency by an amount equal to the intermediate frequency of the receiver.

BASIC DIFFERENCE-FREQUENCY AFC METHODS

The difference-frequency system as applied in missile equipment is based on the characteristics of the reflex klystron, which is the standard local oscillator in missile radar receivers. The operation of the AFC system is such that the local-oscillator frequency is changed automatically when the transmitter frequency changes, with the result that the i-f signal remains constant in frequency.

Figure 5-19 illustrates a block diagram presentation of two AFC circuits. In (A), a single-mixer circuit, a portion of the transmitter pulse is permitted to leak through the TR box and beats with the local-oscillator signal in the mixer. The difference frequency, or i-f signal, is amplified and fed to the discriminator and receiver i-f stages. The discriminator is tuned so that its center frequency is the same as the receiver i-f. The single-ended output of the discriminator is either positive or negative pulses depending on the direction of deviation of the input frequency from the center frequency. The amplitude of the output pulse is determined by the amount of deviation. (Discriminator theory is discussed in detail in *Basic Electronics*, NavPers 10087, chapter 8.)

The output of the discriminator is fed either to a d-c amplifier or some special control circuit which regulates the klystron reflector voltage. The regulation of this voltage changes the frequency of the klystron and enables the local oscillator to operate at the correct frequency.

Figure 5-19 (B) illustrates an AFC circuit using a double mixer. One mixer is used purely for AFC purposes. It is coupled to the transmission line through an attenuator which reduces the transmitter pulse and the received signal by the same ratio. With this arrangement, jamming signals have little or no effect on AFC operation. Both the single- and double-mixer AFC circuits operate on the same principle, that is, by sweeping the klystron repeller plate voltage and adjusting it for changes in transmitter frequency.

Thyratron AFC Circuit

The diagram in figure 5-20 shows a conventional method of automatically controlling the output frequency of a klystron local oscillator. The control circuit consists of two thyratrons and associated circuit components. One thyratron, V_2, functions as a sweep generator, the output of which is attached

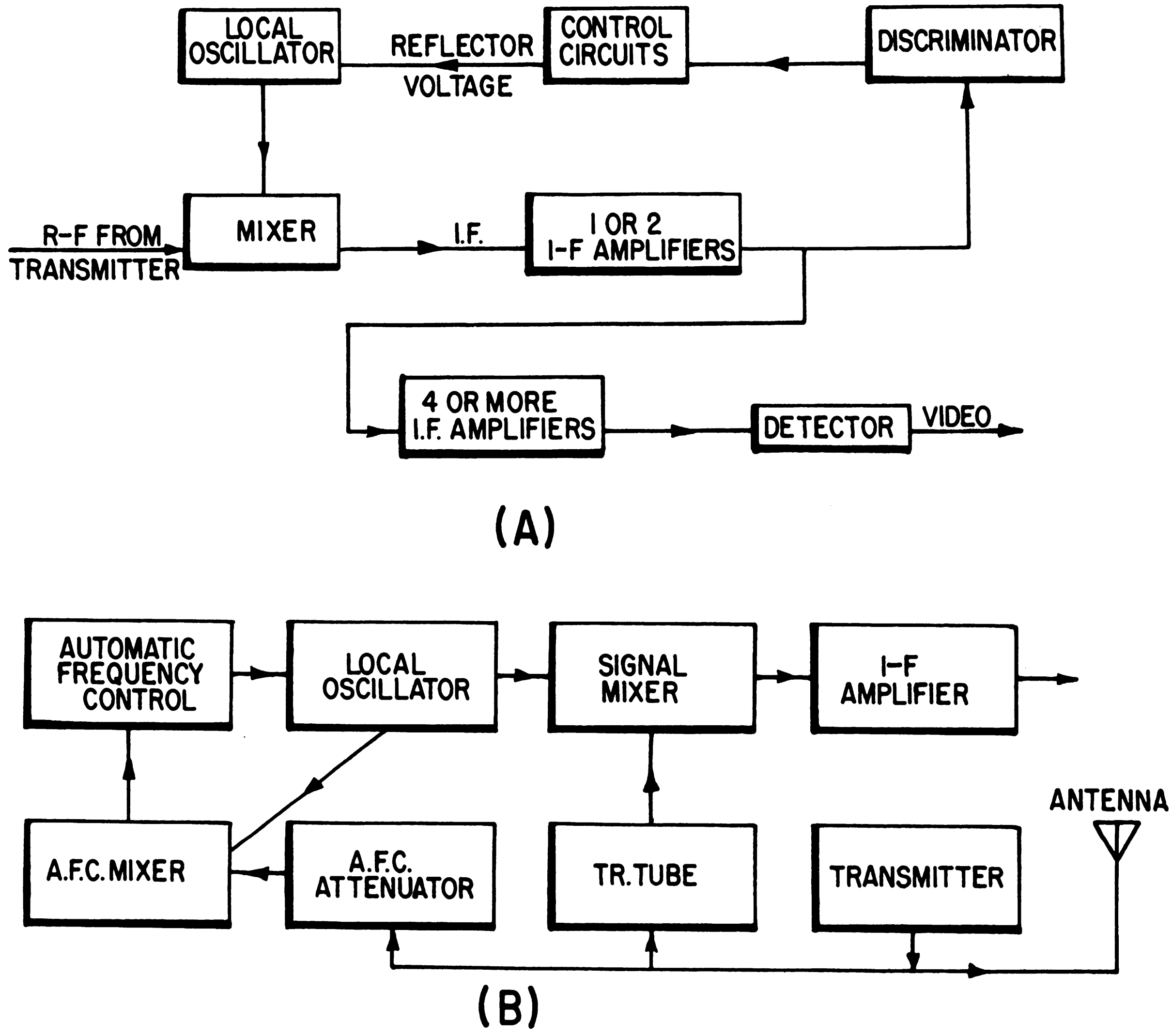


Figure 5-19.—Block diagrams of AFC systems. (A) Single-mixer circuit; (B) double-mixer circuit.

directly to the klystron repeller plate. Lock-in action is obtained by thyratron V_1 when the proper i-f signal is developed.

It should be recalled that in a thyratron, for every value of grid bias, there is a corresponding value of plate voltage which causes ionization. Furthermore, the deionization potential is dependent on the difference voltage between plate and cathode and is a characteristic of the specific tube type. (Additional information on the thyratron as a sweep generator is contained in *Basic Electronics*, NavPers 10087, chapter 7.)

The operation of the circuit of figure 5-20 (A) is described in the following pages. With the transmitter inoperative, the sawtooth voltage applied to the repeller plate causes a wide band of frequencies to be swept by the klystron. The sweep rate, determined by the R-C composed of C_3, R_5, and R_6, is indicated in figure 5-20 (B) as 1 c.p.s., and the repeller voltage varies between minus 100 volts and minus 200 volts. While V_2 is sweeping, V_1 is cut off because of the 30-volt bias developed across R_2 and R_3. This IR drop is part of the voltage divider network consisting of R_2, R_3, and R_4.

Assume that the proper i-f is attained when the repeller voltage is minus 155 volts with the transmitter operating. With this value of reflector voltage, the output of the discriminator is zero, but for any voltage value above

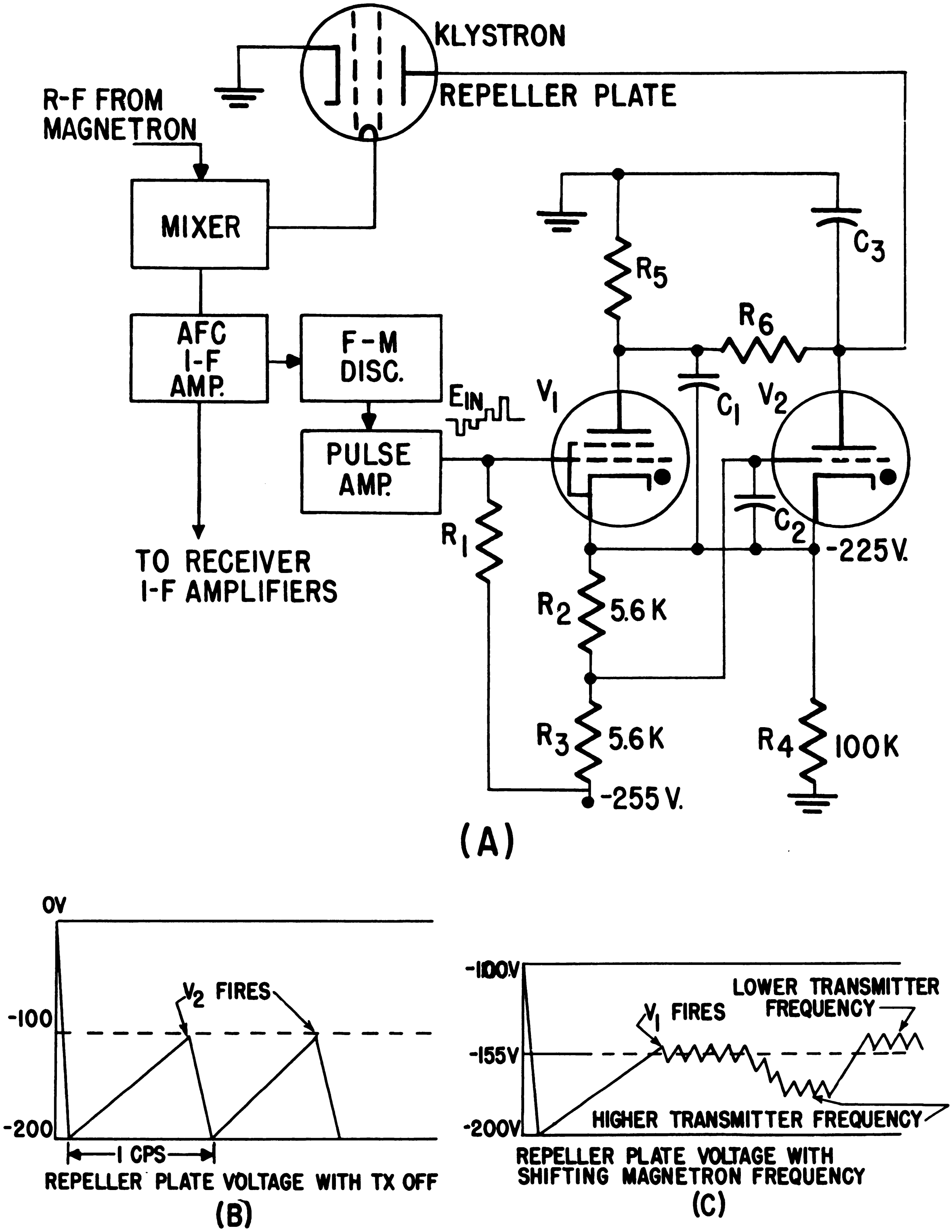


Figure 5-20.—(A) The thyratron AFC circuit; (B) repeller plate voltage with transmitter off; (C) repeller plate voltage with shifting magnetron frequency.

or below minus 155, the discriminator produces an output. When the reflector is more negative than minus 155, the output frequency of the klystron is higher than desired, the input to the grid of V_1 is negative, and the tube remains cut off.

If the reflector becomes less negative than minus 155 volts, the output frequency of the klystron becomes lower than desired and the input to the grid of V_1 goes positive. At some frequency slightly lower than the optimum, the positive pulse input becomes sufficiently large to cause V_1 to ionize. The ionization provides a new charge path for C_3 (through R_3, R_2, V_1, and R_6) and a short discharge path for C_1 (through V_1). The discharge of C_1 causes V_1 to deionize; but before this occurs, C_3 charges to a value slightly more negative than minus 155 volts. When this happens, the input to the grid of V_1 again becomes negative. After V_1 becomes deionized, C_3 again discharges through R_6 and R_5 until the pulse input to V_1 becomes positive and the tube again ionizes. The cycle repeats itself at the rate of about 200 c.p.s.

Figure 5-20 (C) shows the effect of variations of repeller plate voltage on klystron frequency. The resultant frequency variation is only a small fraction of the i-f bandwidth of the receiver. It can be seen in (C) that as the transmitter shifts frequency, the klystron follows so that the frequency fed to the i-f stages is always within the specified range of the amplifiers. The waveform in part (B) indicates that V_2 fires only when the plate voltage reaches minus 100 volts. Thus, it can be seen that the tube is used only to hunt for the proper operating frequency by slowly sweeping the repeller plate voltage. If the proper operating frequency is reached before V_2 fires, as shown in (C), V remains cut off as long as the AFC circuit remains locked on.

MISSILE APPLICATIONS

The circuit shown in figure 5-21 is typical of those used in semiactive homing missiles. The function of this circuit is similar to that of the previously mentioned conventional AFC

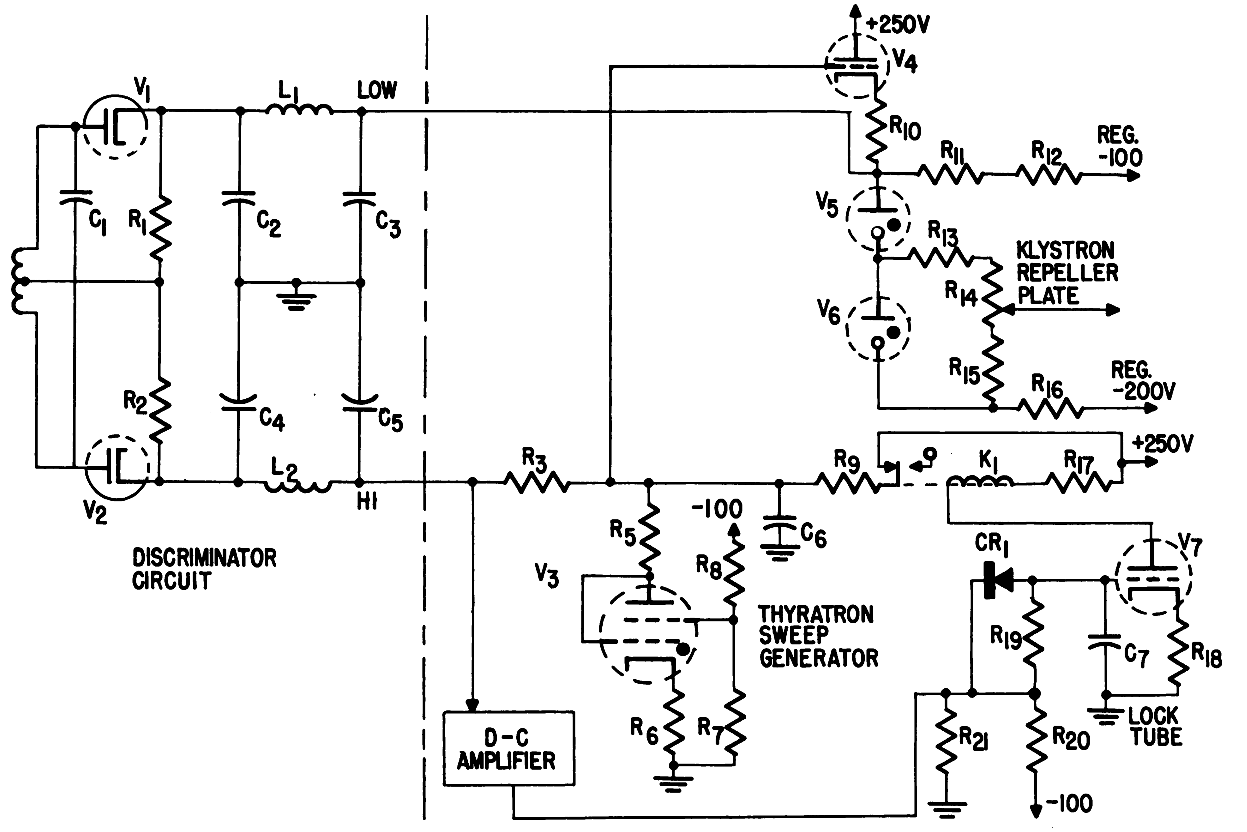


Figure 5-21.—Missile AFC circuit.

circuits. It automatically controls the local-oscillator frequency so that the i-f does not change appreciably.

The klystron, transmitter, and mixer circuits are not shown, but may be considered as conventional circuits which have already been discussed in this chapter.

In order to establish static operating conditions for this circuit, assume that the points designated HI and LOW are shorted together and that K_1 is energized so that no positive potential is applied to the sweep generator, V_3. Under these conditions, an operating bias is established on V_4, the value of which is determined by the current flowing through R_{10}, and the characteristics of the tube. This current is supplied from two sources: First, from the minus 100-volt supply through R_{12}, R_{11}, and R_{10}; and second, from the minus 200-volt supply through R_{16}, R_{15}, R_{14}, R_{13}, V_5, and R_{10}.

V_5 is a gas-type regulator ionized under normal operating conditions. V_6 is also a gas regulator, but is not normally ionized. The voltage drop across R_{15}, R_{14}, and R_{13} may become excessive due to a current surge; in this case, V_6 ionizes momentarily so that the klystron reflector voltage remains within safe limits. Potentiometer R_{14} is adjusted under static conditions so that the klystron oscillates at a frequency near the center of its operating power mode.

In dynamic operation, the circuit functions in the following manner. When power is applied, the deenergized contacts of K_1 permit plate voltage to reach the plate of V_3, the thyratron sweep generator. This tube develops a sawtooth voltage which is applied to the grid of V_4. The sweep rate is determined by the values of C_6 and R_9 and in this case is about 2 or 3 c.p.s. The current through the network between the cathode of V_4 and the supply end of R_{16} likewise varies at the sawtooth rate. Consequently, the reflector voltage on the klystron taken off R_{14} changes at the sawtooth rate across the klystron operating mode.

At some point on the sweep, the difference frequency to the discriminator is such that a positive d-c potential is developed at the point HI. When the potential, amplified by the d-c amplifier reaches a value sufficient to overcome the bias on V_7, this tube, known as the lock tube, conducts and removes the plus 250 volts from R_9 thus disabling the sweep generator. The klystron is then locked on so that only changes in discriminator output affect its output frequency. Changes in transmitter frequency result in changes in discriminator output at the HI and LOW points. These changes are in turn felt at the grid of V_4 and consequently through the resistor network leading to the cathode of the tube and eventually at the klystron repeller plate. Each change in transmitter frequency results in a reflector voltage change designed to maintain the proper intermediate frequency.

Provision for a fade or a momentary loss of signal is incorporated in the lock circuit. C_7 is charged to a high value through R_{19} and R_{20} when V_7 is cut off. When the d-c amplifier output goes positive, CR_1 conducts and the capacitor discharges through the short R-C which includes CR_1 and R_{21}. This permits V_7 to conduct and provide an instantaneous lock on. If the signal is momentarily lost, the circuit does not unlock immediately and allow the sweep thyratron to go into operation. Instead, C_7 must charge to the full cutoff bias voltage through the long R-C path which includes R_{19} and R_{20}. The delay in circuit unlock gives the input signal time to return before sweep action is commenced. Thus, the circuit provides a fast lock, but a slow unlock.

Coincidence Circuits

In some missile control circuits, it may be desirable to have certain elements operate only under specified conditions, or at specific times in relation to a reference time. This can be accomplished through the use of the coincidence amplifier. Only the coincidental arrival of two separate accurately timed signals can drive the circuit into operation from its normal cutoff status.

Coincidence amplifiers basically are merely amplifiers which are biased beyond cutoff. When two signals are applied to the tube in such a manner as to overcome the bias, the tube conducts and produces an output. Coincidence can be accomplished by applying the input signals to several combinations of tube elements.

A sample circuit is presented in figure 5-22 (A) utilizing a grid-cathode combination to

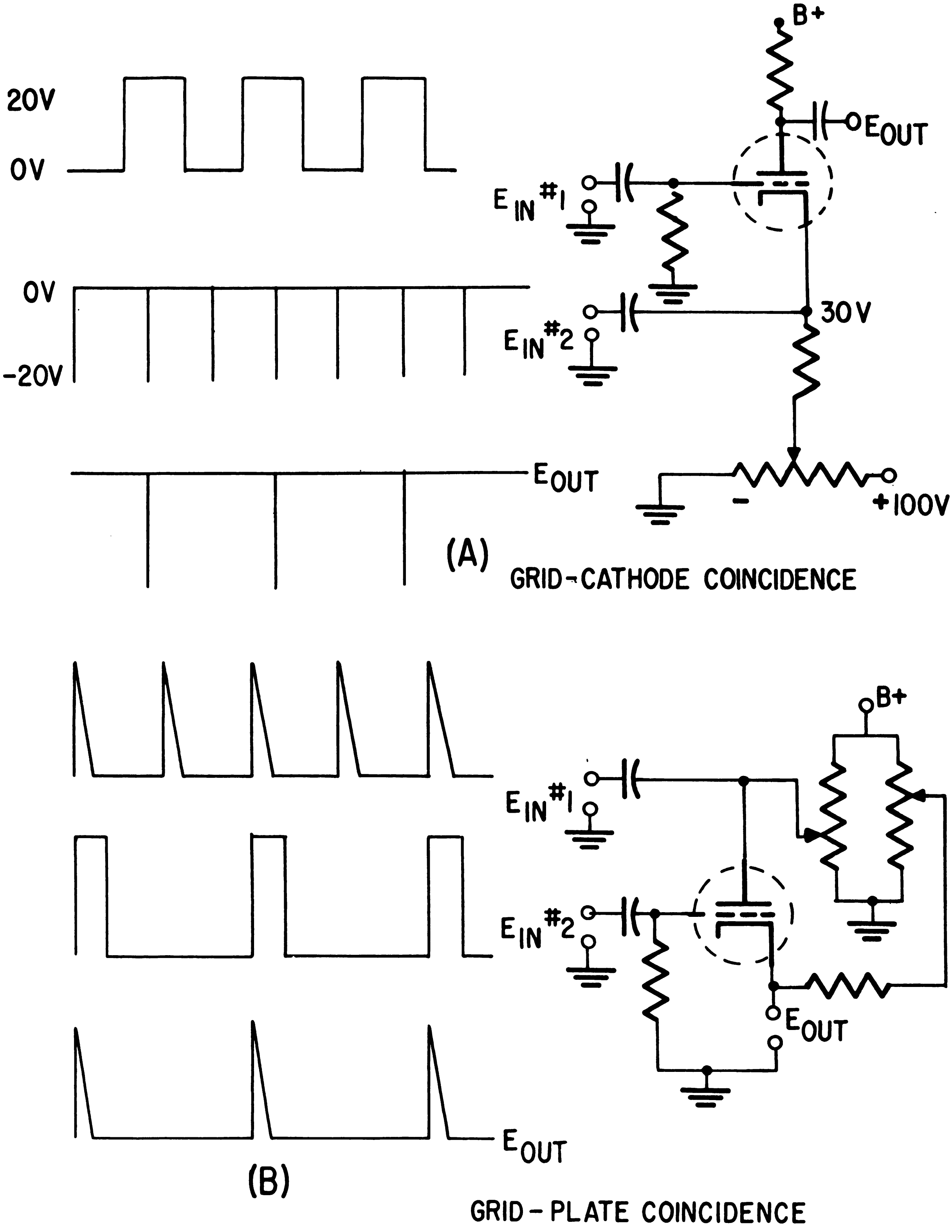
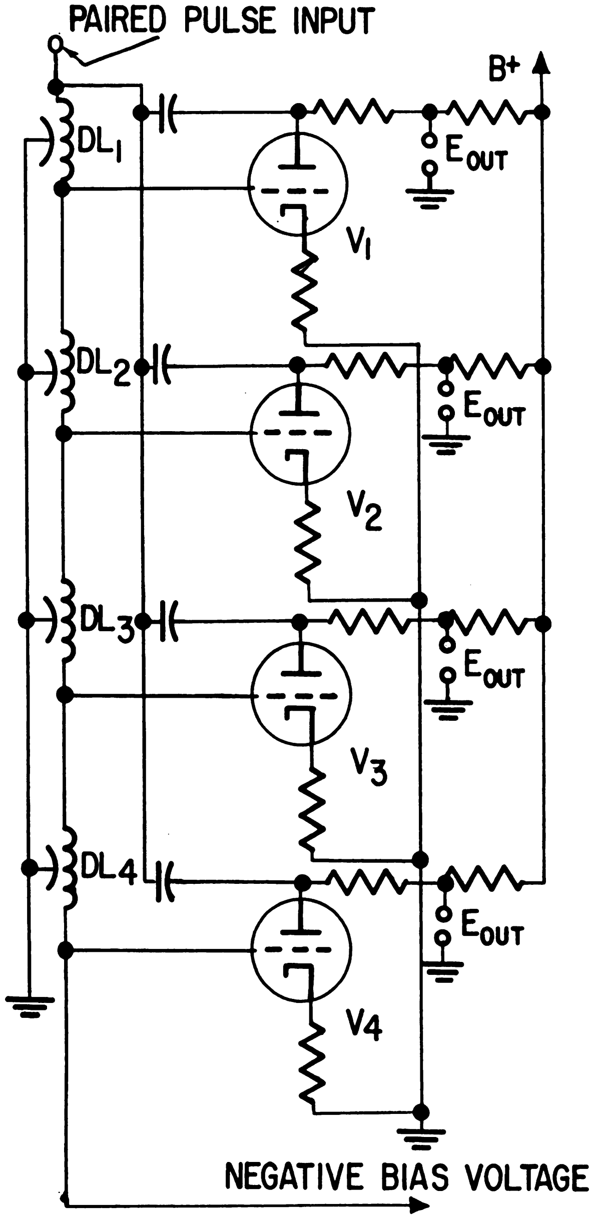
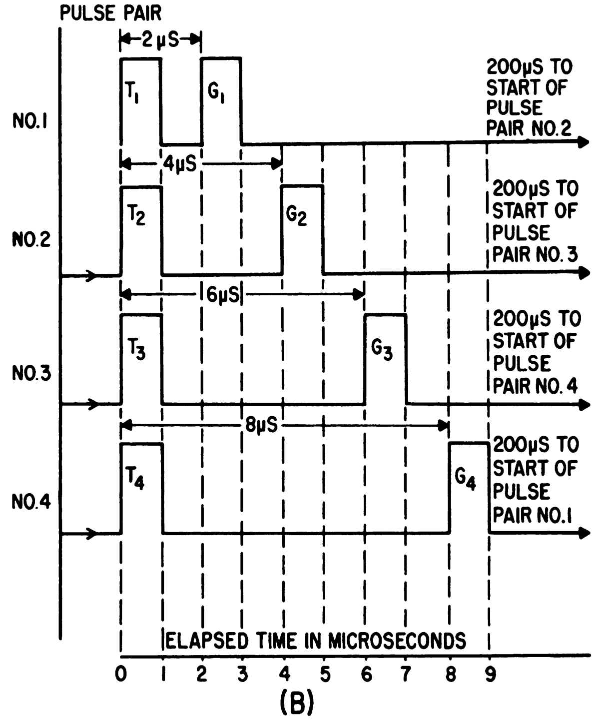


Figure 5-22.—Typical coincidence circuits.



(A)

Figure 5-23.—(A) Demodulator using coincidence amplifiers.



(B)

Figure 5-23.—(B) Time relationship in coincidence demodulators.

achieve the desired results. Under nonconducting conditions, the voltage divider places the cathode of the tube at a positive 30 volts above the grid and the tube is cut off. If, with no grid signal, a negative 20-volt signal arrives at the cathode, ($E_{in\#2}$), the amplitude is not great enough to overcome the bias and the tube remains cut off. And, if, with no cathode signal applied, a positive 20-volt signal is placed on the grid ($E_{in\#1}$), the same situation prevails. However, if both grid and cathode signals arrive simultaneously, the total amplitude causes conduction, but only for the period of time when both signals are at their respective elements. The input signal may be square-wave in form; but to insure accurate timing, at least one signal should be short and sharp, as in a series of peaked waves.

The control grid-plate circuit in figure 5-22 (B) operates in a manner similar to the grid-cathode circuit except for the manner by which the tube is held nonconducting. A fixed potential is applied to the cathode, and a potential lower in amplitude is applied to the plate. With no input signals, the tube is nonconducting for two reasons: One, the grid-cathode difference exceeds the cutoff value; and two, the plate is more negative than the cathode and presents no attraction to electrons. If a positive pulse arrives at the grid and the amplitude is sufficient to overcome the bias, the grid may draw current depending on the amplitude of the pulse, but plate current does not flow. A positive pulse applied to the plate and sufficient to raise the plate potential above the cathode still does not cause conduction because of the

bias. However, both pulses arriving in coincidence overcome both the bias and the low plate voltage, and conduction does occur.

If the incoming signals are such that they can never coincide naturally, one signal can be delayed by means of an artificial delay line to attain coincidence. This system may be applied to all types of coincidence amplifiers.

A simplified missile circuit utilizing the coincidence amplifier is illustrated in figure 5-23 (A). The circuit functions as a demodulator to separate reference times occurring in a complete cycle of transmission and produces an output in proportion to relative signal strength. The input to the circuit is shown in figure 5-23 (B) and indicates one complete transmitted cycle as being 800 microseconds in duration.

At the beginning of the cycle, pulse T_1 appears at the plates of all tubes and at the top of the delay line network. Due to the bias voltage, no conduction occurs in any tube at this time. The pulse starts down the delay line where it is subjected to a 2-microsecond delay in time in each section. Thus, the pulse does not appear at the grid of V_1 until after 2 microseconds have elapsed. At this time, pulse G_1 is applied to the plates of all tubes simultaneously; and since V_1 now has a pulse on the plate and a pulse on the grid sufficient to override the bias, the tube goes into conduction for the period of coincidence. Pulse T_1 continues down the delay line and arrives at the grids of V_2, V_3, and V_4 at the start of microseconds number 4, 6, and 8, respectively. At these times, pulse G_1 has expired and the three latter tubes do not conduct. No additional pulses arrive until the start of the 200th microsecond.

At the start of the 200th microsecond, pulse T_2 arrives and is applied to all the plates and the delay line simultaneously. No conduction occurs because no tube fulfills the conditions necessary for coincidence. The pulse arrives at the grid of V_2 at the start of the 204th microsecond and, at the same time, pulse G_2 is applied to all plates and the delay line. V_2 at this time has coincidental plate and grid pulses and therefore conducts while the other tubes remain cut off. At later times in the cycle, pulse pair #3 causes V_3 to conduct, and pulse pair #4 causes V_4 to conduct. From the foregoing, it can be seen that each tube conducts in order and that during one complete cycle, each tube conducts for the period of one microsecond.

The output amplitude of each tube is determined by the amplitude of the inputs so that a position error can be determined by the difference between two pulse amplitudes. For instance, if paired pulse #1 is termed "right" and paired pulse #3 is termed "left," then equal output amplitudes indicate zero error, while a difference in output amplitude indicates that the missile is off course in one direction.

Target Detecting Components

The coincidence demodulator, as well as the AFC circuits, klystrons, balanced mixers, and magnetrons described previously are examples of electronic equipment used in missile guidance and control systems. The operation of all these devices depends directly or indirectly upon signal information derived originally by the target detecting section of the missile. This section differs widely in different types of missiles, but in general contains elements which send or receive electromagnetic waves. Typical components include radar transmitting antennas, receiving antennas, and devices for detecting infrared radiation. The remainder of the chapter is concerned with the operating principles of fundamental elements employed in this section of the missile and which comprise an essential part of the guidance system.

OPERATING PRINCIPLES OF DIRECTIONAL ANTENNAS

Antennas in air-launched missiles are primarily of the directional type. This term is applied to a radiating or receiving system which transmits electromagnetic waves in relatively narrow beams or receives waves within a small angular area. In pulse-radar equipment, the same radiator is generally employed for both transmission and reception; while c-w radar systems contain separate transmitting and receiving antennas. In either case, the directional feature is essential since it makes it possible to illuminate comparatively small targets with good resolution and to determine target position from the bearing of the receiving antenna when echo signals are received. In addition, highly directional

reception assists in minimizing interference from unwanted radiations such as enemy countermeasures and from ground return.

The basic principles of antenna operation and the electrical characteristics of the Hertz, Marconi, and dipole antennas are discussed in *Basic Electronics*, NavPers 10087, chapter 11. The reader is requested to read this chapter for the necessary background information. The parasitic array is discussed here to introduce the principles involved in producing narrow beams of radiated energy. This is followed by descriptions of the parabolic reflector, and the slot antenna which are of fundamental importance in microwave missile applications.

Parasitic Array

The parasitic array is an antenna system composed of two or more elements, one of which is driven or excited directly by the transmitter. The other element (or elements) receives excitation by induction and radiation fields produced by the driven element. With elements of the proper length and spacing, the operation of the array makes it possible to obtain highly directional radiation patterns.

If an antenna slightly longer than half a wavelength and connected to a power source is placed parallel to and less than a wavelength from a driven half-wave antenna, it acts as a parasitic reflector. The optimum distance is between 0.15 and 0.25 wavelengths. The undriven element absorbs power and reradiates it with such a phase relationship to the original radiation that the fields of the two add in one direction and subtract in the other. If the two elements are spaced 0.25 wavelengths apart as illustrated in figure 5-24, the radiation pattern of (A) results. This shows that most of the radiation is on the side of the driven element which is furthest removed from the parasitic element.

A parasitic element shorter than a half wavelength, placed parallel to and less than a quarter wave from a driven element is a parasitic director. The director absorbs energy and reradiates it with such a phase relationship that the fields of the two elements add in the direction shown in figure 5-24 (B). Both parasitic directors and reflectors can be used in the same antenna system to obtain required directional patterns.

Directivity of Antenna

The directivity of an antenna system refers to the sharpness or beam width of the radiation pattern. An antenna with a sharp pattern in the horizontal plane has good horizontal directivity while a vertical pattern antenna exhibits equally good directivity in the vertical plane. Directive transmitting antennas retain similar characteristics for receiving.

A wide variety of field patterns can be obtained with a simple directional system containing only one parasitic element. Two variables can change this pattern: One, the length or tuning of the parasitic element; and two, the spacing between the parasitic element and the driven element.

A parasitic reflector should be spaced one-quarter wavelength from the driven element to provide the required cancellation and reinforcement of the radiation from the driven

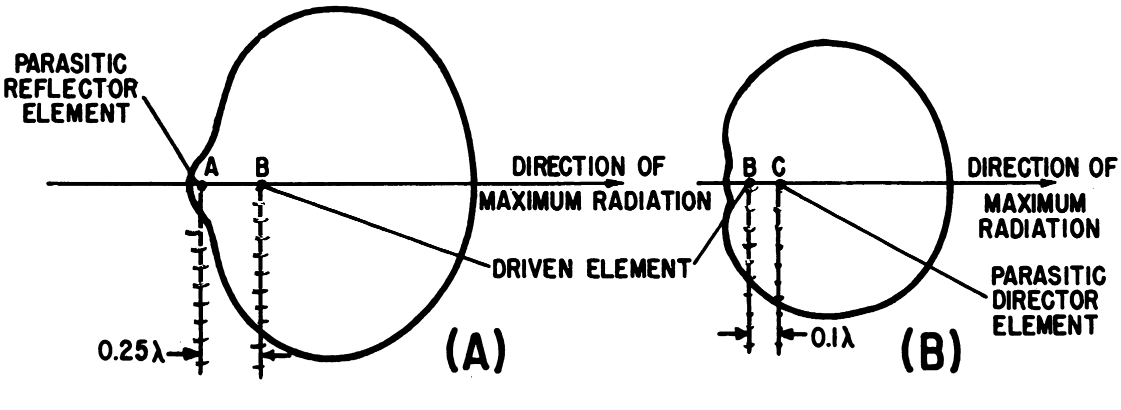


Figure 5-24.—Radiation patterns. (A) Pattern from a driven element and reflector; (B) pattern from a driven element and director.

element. However, if the physical spacing is made less than a quarter wavelength, the required time delay must be provided by electrical means. This process is an application of the fact that current lags in a circuit which is predominantly inductive and leads in a circuit which is predominantly capacitive. Therefore, if a reflector is placed less than one-quarter wavelength behind the driven element, (for example, one-eighth wavelength or 45°), the current in this element can be made to lag by the same amount. Hence, the resonant frequency of the reflector must be made slightly lower than that of the driven element so that it is sufficiently inductive at the operating frequency to produce the required 45° current lag. The reflector then must be slightly longer physically than the driven element.

A similar consideration shows that when a parasitic director is spaced less than one-quarter wavelength in front of the driven element, the length must be made slightly less than that of the driven radiator. It then acts as a capacitive reactance and causes the current in the director to lead. It should be tuned to provide the required lead in current which will cause the waves to add in the forward direction.

Power Gain of Antennas

Power gain is a term used to express the increase in power of one antenna over a standard antenna used for comparison, usually a half-wave element having the same polarization as the antenna under consideration. Power gain of directional antennas is usually measured in the optimum direction of radiation and is sometimes called the power ratio. In this case, either the power ratio of the two antennas may be indicated, or the ratio of the front to back radiation from a unidirectional array may be indicated.

Figure 5-25 shows the effect of element spacing on the power gain of an array compared with the field strength of a half-wave antenna alone. Curve A shows the power gain for director spacings in wavelengths between a half-wave director and the driven half-wave radiator. Curve B shows the power gain for half-wave reflector spacings between the reflector and the driven half-wave element. Note that a reflector provides only a small amount of gain when spaced at a distance of 0.1 wavelength from the driven element and that the gain falls off sharply when the spacing is decreased. The director, however, may have considerable gain at much smaller values of spacing.

Multielement Parasitic Arrays

Several parasitic elements can be used in conjunction with a driven antenna to further increase directivity and power gain. The number of reflectors is usually limited to one, while the directors can be any reasonable number with the average tending to be about four. The theoretical gains of directional arrays composed of an excited element and various numbers of parasitic elements are given in the following list:

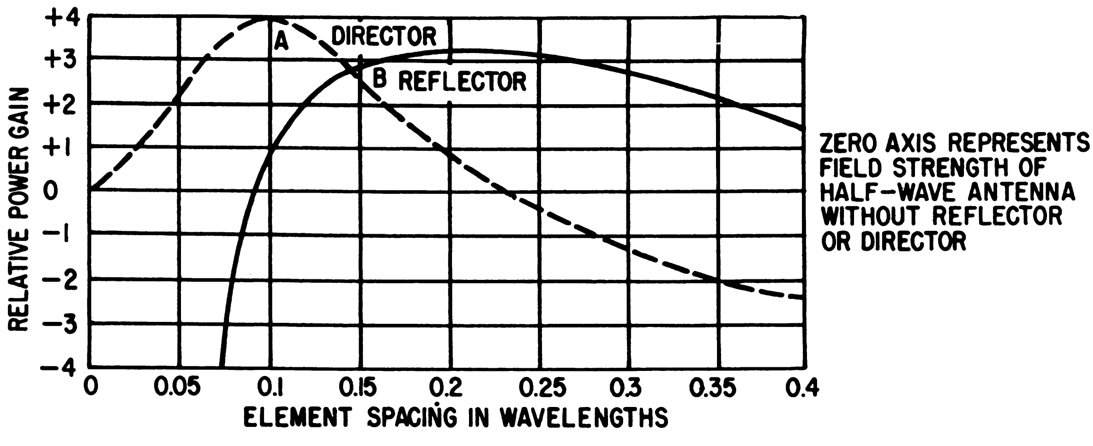


Figure 5-25.—Relative power gains of parasitic arrays for different reflector and director spacings.

Number of elements	Power gain
2	2.5
3	3.6
4	5.0
5	6.4

From these figures it is apparent that multielement arrays make desirable radiators when powerful unidirectional beams with minimum front-to-back ratios are required. The type of radiation produced by such an array is indicated in figure 5-26.

Beam Angle

Comparisons between the more directive types of antennas are usually made in terms of beam angle. This is the angle between the half-power directions, or the directions at which the electric field strength is 0.707 of maximum. The radiation patterns of two directional antennas are illustrated in figure 5-27. The beam angle for pattern M, the pattern of one of the antennas, is much narrower than that of L, the pattern of the other. Points A and B in pattern M represent the two half-power points where the field strength is 0.707 of the value at point C. The points of corresponding value on pattern L are marked X and Y. In the field of missile operation, high degrees of directivity are requisite; and the principal characteristic of interest in a particular antenna is often the narrowness of the beam angle.

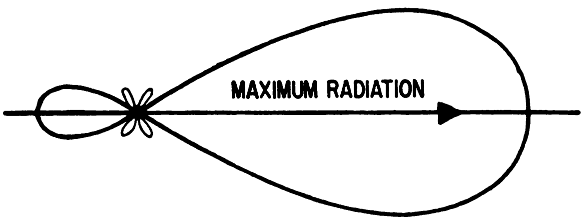


Figure 5-26.—Field pattern produced by a multielement array.

MICROWAVE ANTENNA SYSTEMS

The operating principles of antennas suitable for microwave frequencies are the same as for antennas designed for lower frequencies. The major difference in the two classes is in the physical size of the radiators. Microwave directive arrays containing several parasitic elements can be constructed so as to occupy a small space; and the properties of these waves make it possible to employ parabolic

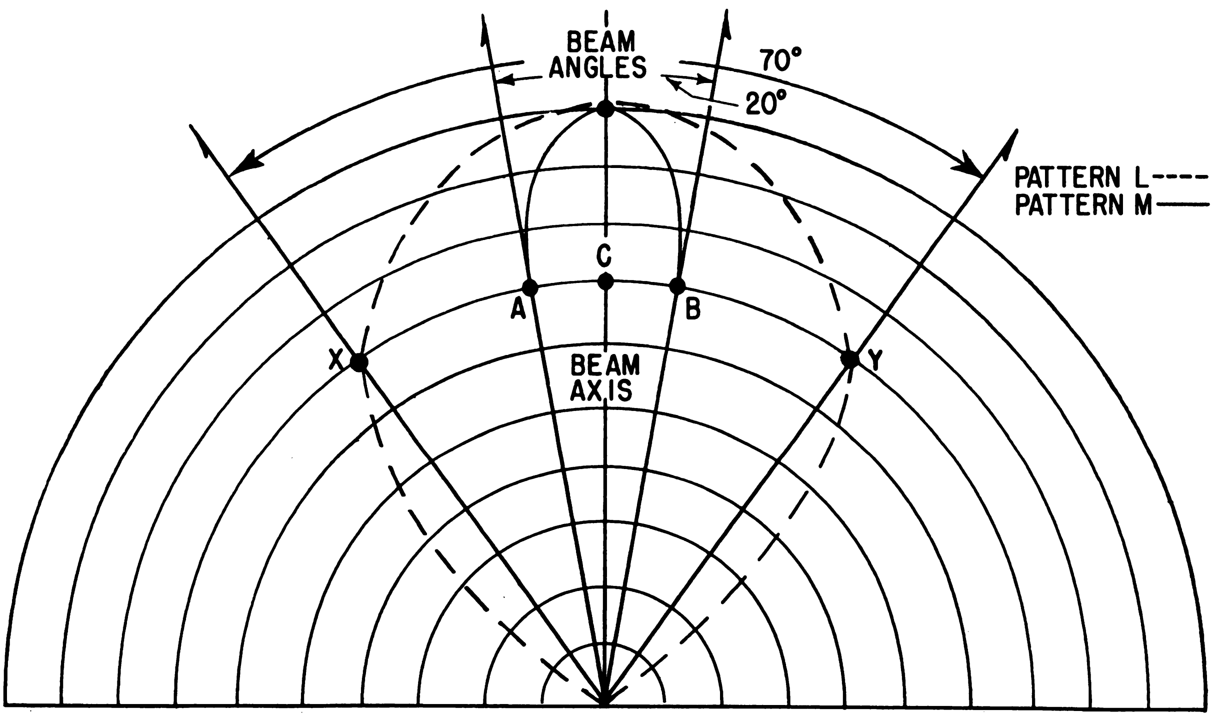


Figure 5-27.—Antenna beam angles.

reflectors and slot antennas, which would be impractical for use at lower frequencies.

Parabolic Reflectors

Microwaves have characteristics very similar to those of light waves; and as a result, parabolic reflectors are widely used at these frequencies for obtaining high degrees of directivity. The basic property employed is illustrated in figure 5-28: all waves originating at the focal point and moving toward the curved surface are reflected from it as parallel rays. (Conversely, all parallel rays striking the surface are brought together at the focal point.)

A form of the parabolic reflector that is often applied in microwave systems is the rotational parabola, or paraboloid of revolution. This surface is generated by rotating the parabolic curve (shown in fig. 5-28) about the axis 0 - 0'. The resulting surface is somewhat similar to the large end of an eggshell when cut in half. The reflector is used in conjunction with a small vertical dipole antenna which is located at the focal point of the parabola. A hemispherical shield placed on the side of the vertical dipole away from the parabolic reflector serves to direct all the radiation back toward the parabolic surface. Without the shield, some of the output of the exciting antenna is radiated directly and does not become part of the main beam; but with the combination of all three elements, the overall effect is to concentrate the microwave output into a narrow ray in much the same manner as a searchlight reflector controls a light beam.

The method of eliminating direct radiation from the antenna can be performed by the use of a parasitic array instead of a hemispherical shield. The radiation pattern of a rotational parabola, in addition to minor lobes, contains a major lobe which is directed along the axis of revolution. These are shown in figure 5-29. Utilization of the parabolic reflector makes possible a very narrow beam.

Another form of parabolic reflector is the cylindrical parabola with open or closed ends. These reflectors have a parabola curvature in one plane, usually the horizontal, and no curvature in any plane perpendicular to the plane of curvature. Normally this type of parabola is excited by an antenna placed parallel to the cylindrical surface and located at the axis of the parabola. The parabola should be so designed that the focal point lies well within its mouth in order that most of the radiated energy be intercepted by the reflecting surface.

Slot Antennas

The slot antenna consists of a radiator formed by cutting a narrow slot in a large metal surface. Such an antenna is shown in figure 5-30. The slot wavelength is a half wave while the width is a small fraction of a wavelength. An antenna of this type is frequently compared to a conventional half-wave dipole consisting of two flat metal strips whose sizes are such that they would just fit into the cutout slot. This comparison is made since the radiation pattern produced by the slot and that of the complementary dipole are the same.

It is of interest to note an important difference between the slot and the dipole; namely, the electric and magnetic fields are interchanged. In the case of the dipole antenna

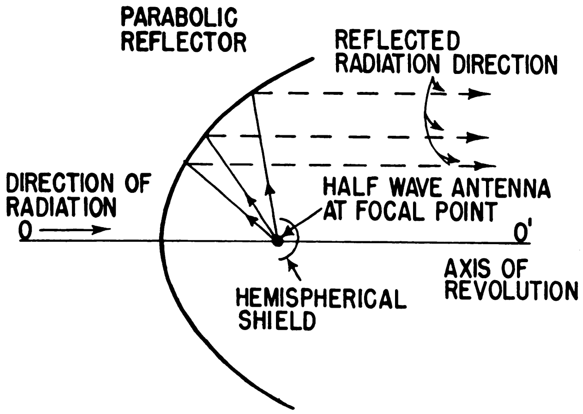


Figure 5-28.—Parabolic reflector.

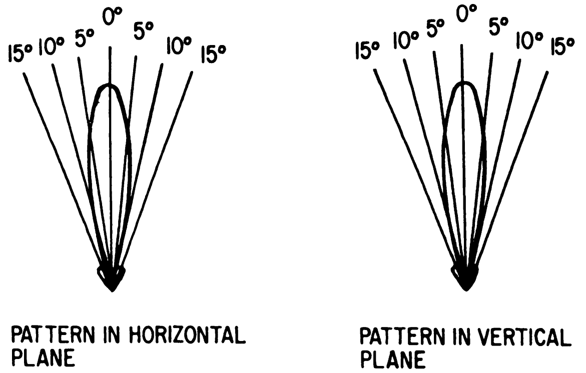


Figure 5-29.—Typical directional pattern obtainable with rotational parabolic antenna.

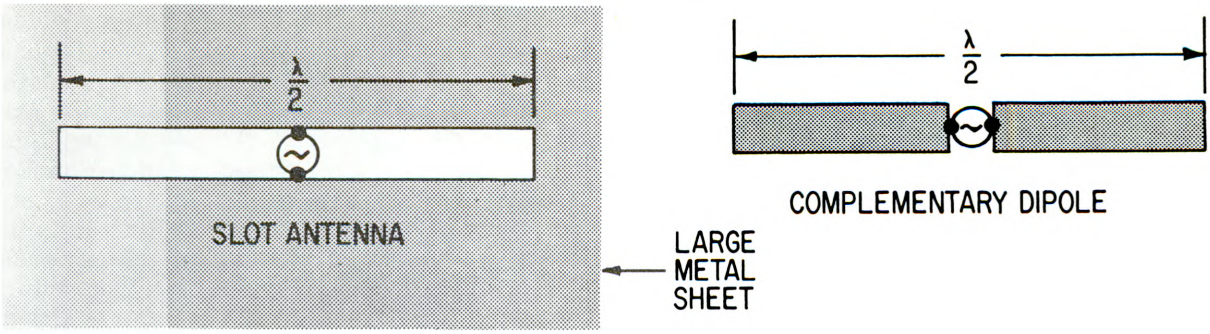


Figure 5-30.—Slot and complementary dipole antenna.

shown, the electric lines are horizontal while the magnetic lines form loops in the vertical plane. In the slot antenna, the magnetic lines are horizontal and the electric lines are vertical and built up across the narrow dimension of the slot. As a result, the polarization of the radiation pattern produced by the horizontal slot is vertical as opposed to the horizontal polarization of a horizontal dipole.

When energy is applied to the slot antenna, currents flow in the metal sheet. These currents are not confined to the edges of the slot, but rather spread out over the sheet. Radiation then takes place from both sides of the sheet.

Coaxial lines are often used to feed slot antennas. The outer conductor is bonded to the sheet while the inner conductor is connected to the opposite side of the slot as shown in figure 5-31.

Note that the coaxial line is not connected to the center of the slot since a severe impedance mismatch would occur. The impedance

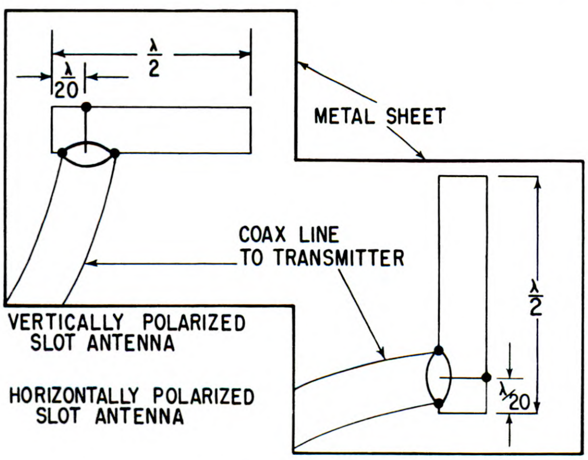
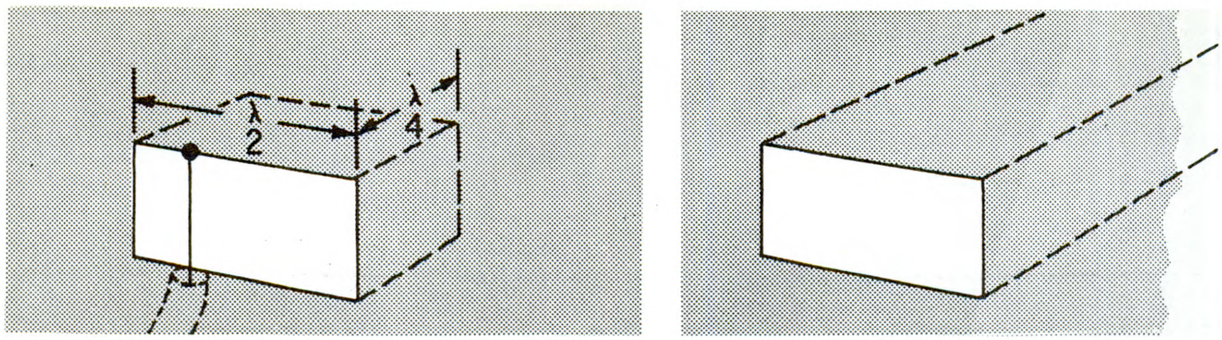


Figure 5-31.—Feeding slot antennas.

at the center of a slot with an electrical length of approximately one-half wave and a width of about 0.01 wavelength is about 530 ohms. The impedance is lower at points nearer the end of the slot. Thus, if the feed line is connected about one-twentieth wavelength from the end, the input impedance matches the line impedance since the former has a value of 50 ohms at that point. If it is necessary to connect the feeder line at the center of the slot, the slot length must be greater than one-half wave (a length of one full wave results in a 50-ohm impedance at the center).

Frequently it is desired to produce radiation from one side of the sheet only. This is accomplished by boxing in the slot with a section of waveguide. If the depth of the waveguide is equal to a quarter wavelength, as shown in figure 5-32, the added section functions as a pure resistance. Under these conditions, the input impedance at the center of the slot is about 1,000 ohms, while the impedance at a point one-twentieth wavelength from either end is approximately 100 ohms. An alternative method of making the slot antenna radiate from one surface only is also illustrated in figure 5-32. This consists of feeding the antenna by means of a waveguide, which eliminates the coaxial feeder assembly.

It has been mentioned that the radiation pattern produced by a slot antenna is the same as that produced by a complementary dipole antenna. This is true only if an infinitely large metal sheet is used. If the vertical size of a sheet containing a vertically polarized slot is reduced, the amount of radiation that occurs at small angles to the plane of the sheet is likewise reduced. This is shown in figure 5-33. The radiation pattern produced by a complementary dipole in the plane



BOXED–IN SLOT ANTENNA

WAVEGUIDE–FED SLOT ANTENNA

Figure 5-32.–Unidirectional slot antennas.

perpendicular to the antenna is also shown for comparison. The pattern shown is observed from the end of the dipole. If all the radiation to the left of the vertical centerline should disappear, the resultant would resemble the radiation pattern of the boxed-in slot antenna. (See fig. 5-33 (A).) In this view, the edge of the metal sheet in which the slot is cut is shown. The length of the slot is at right angles to the plane of the page, and the radiation patterns are shown in the plane of polarization of the energy.

If the vertical size of the sheet in this case is a little over 5 wavelengths, the scalloped pattern shown in figure 5-33 (B) results. As the size of the sheet is reduced to slightly over 2-1/2 wavelengths, fewer irregularities appear in the pattern as shown in (C). Also note the reduced radiation at a fixed angle (shown as 30°) with respect to the metal surface. At a vertical size of about a half wavelength, the pattern shown in (D) bears little resemblance to that indicated in (A) in that the radiation inside the 30° angle is considerably reduced. In practice, since the size of the sheet from which the slot is cut is usually quite large compared to the size of the slot, radiation patterns having a form between those shown in (A) and (B) are most common.

A different form of slot antenna is shown in figure 5-34. In this system, the large metal sheet is eliminated and replaced by an array of diagonal slots cut into a length of waveguide. The slots are spaced at intervals along the waveguide so that they are excited in phase. Maximum radiation then takes place in the direction indicated.

When a slot antenna is installed, particular attention should be paid to the slot location with respect to large surrounding objects. Wings, fuselage, tail surfaces, or engines can cut off a large portion of the radiated or received energy if these objects are located between the antenna and the target.

PHOTOELECTRIC CELLS

The photoelectric cell belongs to a class of radiation-sensitive devices that differ completely from microwave sensing elements. It is capable of response to radiation within the visible range of the spectrum and thereby is an element which extends the field of applied electronics to include optics. While the application of photocells in air-launched missile systems is extremely limited, these devices are of interest for the missileman because of their importance in the general area of electronic science.

The principle upon which photoelectric cells operate was discovered near the end of the 19th century by Heinrich Hertz, who found that electrons are emitted from the surfaces of certain metals when these are exposed to strong beams of light. The substances which exhibit this property to the highest degree belong to the family of alkali metals which includes potassium, cesium, and sodium. When these materials are illuminated by beams of light, energy is absorbed by the free electrons present near the surfaces; and if the quantity of energy imparted by the light is sufficiently great, the electrons are released, becoming photoelectrons.

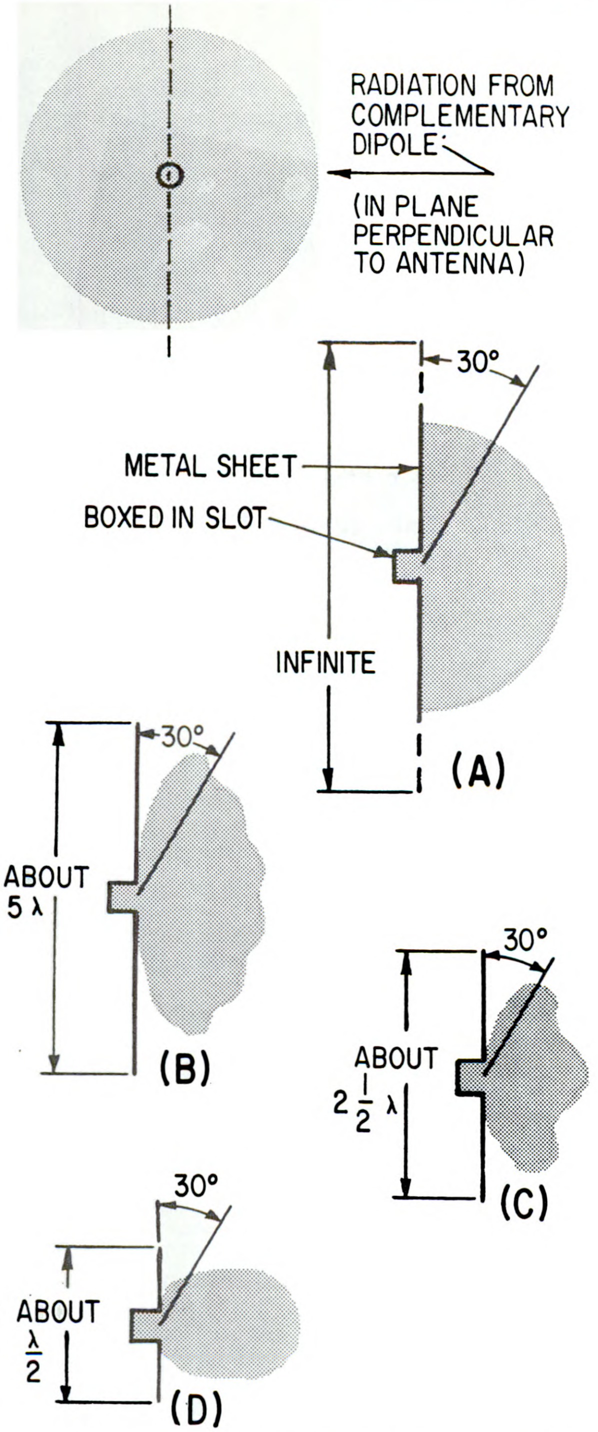


Figure 5-33.—Radiation pattern from boxed-in slot antenna.

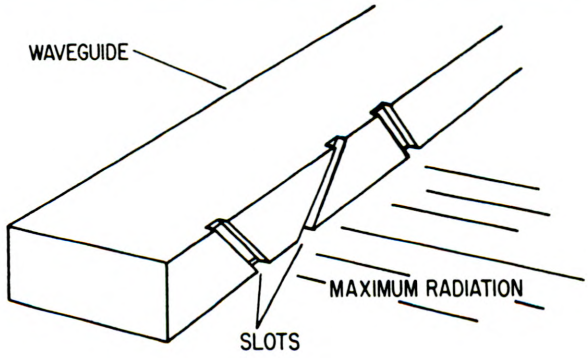


Figure 5-34.—Slot array.

In its most common form, the photoelectric cell is composed of two elements: a cathode usually constructed as a curved surface coated with the photoemissive material; and an anode located at the center of the circle defined by the cathode. As light impinges upon the cathode, it emits photoelectrons which are collected by the anode. The latter is operated at a positive potential which ranges from about 15 to 20 volts, this being sufficient to collect all the electrons emitted.

The laws governing the operation of the photoelectric cell, which are of basic importance in atomic and nuclear studies, can be stated simply in the following form:

1. The number of electrons emitted from the cathode is directly proportional to the intensity of the light falling upon the emitting surface.

2. The velocity of the emitted electrons is independent of the light intensity and depends only upon the type of cathode surface and upon the wavelength of the incident light.

Although the photocell is seldom applied in air-launched systems, a device closely related to it provides the primary target sensing element in some passive homing missiles. This is the photoconductive cell, the resistance of which is varied by the action of infrared radiation. Information concerning the use of this type of element in missile seeker heads can be found in *Aviation Guided Missileman 3 and 2,* NavPers 10379, chapter 4.

QUIZ

1. The cavities in a magnetron
   a. will oscillate naturally at the same frequency
   b. are strapped together to oscillate in the pi mode
   c. have adjacent segments connected to force oscillation in the dominant mode
   d. are electrically 90 degrees apart when operating in the dominant mode

2. In the case of a magnetron, the required shock excitation is provided when a/an
   a. strong d-c field is applied
   b. strong a-c field is applied
   c. strong magnetic field is applied
   d. r-f field is applied

3. A magnetron will produce output energy over a range of frequencies determined primarily by the
   a. transit time frequency-limiting factor
   b. magnitude of anode and repeller voltages
   c. strength of the applied magnetic field
   d. number and physical dimensions of the resonant cavities

4. The most desirable mode of operation in a magnetron occurs when the phase difference between any two adjacent anode segments is
   a. 45 degrees
   b. 90 degrees
   c. 135 degrees
   d. 180 degrees

5. Magnetron oscillating cavities contain the combined effect of
   a. magnetic and d-c fields
   b. magnetic and r-f fields
   c. magnetic, d-c and r-f fields
   d. d-c and r-f fields

6. When operating in the pi mode, the magnetron space charge rotates at an angular velocity
   a. of two poles per cycle
   b. of 2f
   c. equal to the operating frequency
   d. at the speed of light

7. A magnetron is seasoned to
   a. seal out minute cracks in metal and glass
   b. permit tube operation without arcing
   c. prevent irregularities in the magnetic field
   d. warp the pole pieces back into shape

8. The switching devices used in radar systems which make it possible to transmit and receive microwave pulses with a single antenna are
   a. thyratrons
   b. TR and ATR tubes
   c. electronic lobe switches
   d. rotary spark gaps

9. Recovery time is an important operating characteristic of the TR tube because it determines
   a. maximum range
   b. p.r.f.
   c. rest time
   d. minimum range

10. Which of the following conditions exist in a duplexer when a pulse is transmitted?
    a. TR and ATR tubes are deionized
    b. TR and ATR tubes are ionized
    c. TR ionized, ATR deionized
    d. TR deionized, ATR ionized

11. During receive time, the TR and ATR tubes operate so that
    a. the TR will ionize
    b. the ATR will ionize
    c. both will deionize
    d. both will ionize

12. One of the following is <u>not</u> an operating characteristic of a good duplexer. It
    a. dissipates little power compared to the transmitter
    b. maintains a proper impedance match in the transmission line when fired
    c. deionizes slowly to permit reception of "close-in" target signals
    d. affords sufficient power attenuation to prevent receiver damage

13. A TR tube is used to protect the
    a. receiver from the transmitter during transmit time
    b. ATR from the transmitter during transmit time
    c. transmitter during receive time from nearby radar transmitters
    d. antenna from the transmitter

14. Careful tuning of TR and ATR tubes is necessary because the cavities function as high-Q tank circuits. Tuning is accomplished by varying the
    a. pressure of the gas
    b. keep-alive voltage
    c. current through the cavity
    d. spacing between the main electrodes

15. In the microwave region, ordinary vacuum tubes are not suitable for use as converters or detectors because of the large
    a. amounts of internal noise they generate, and transit-time losses
    b. gain they produce, and frequency response
    c. size of the vacuum tube, and the type of tube base
    d. amount of internal noise, and frequency instability

16. A radar local oscillator must be stable and also
    a. fixed to one particular frequency
    b. produce high output voltage
    c. produce high output power
    d. tunable over a range of frequencies

17. The cavity of a reflex klystron functions as
    a. a series resonant circuit
    b. a parallel resonant circuit
    c. a series-parallel resonant circuit
    d. two resonant circuits in series

18. A reflex klystron is a
    a. frequency-modulated tube
    b. amplitude-modulated tube
    c. velocity-modulated tube
    d. phase-modulated tube

19. In typical reflex klystron operation, the
    a. resonant frequency will vary with repeller voltage changes
    b. electrical bandwidth will decrease as the mode order increases
    c. transit time determines the power output in any mode
    d. power output will decrease as the transit time increases

20. A double-mixer AFC circuit is preferred to a single mixer because it
    a. requires fewer components
    b. is less subject to jamming
    c. does not need a local oscillator
    d. will compensate for a wider frequency drift

21. Refer to figure 5-20 (A). During AFC operation, after lock, C_1 will be discharging during the period when
    a. the klystron repeller is too negative
    b. V_2 is conducting
    c. the input to V_1 is negative
    d. C_3 is charging

22. Refer to figure 5-20 (A). When the circuit shown breaks into lock,
    a. V_2 will conduct steadily
    b. V_1 will conduct intermittently
    c. C_1 will take on a steady negative charge
    d. the discriminator will have a steady zero output

23. When the discriminator in figure 5-21 has sufficient HI output, V_7 will conduct,
    a. V_4 will increase conduction, and K_1 will energize
    b. V_3 will cut off, and K_1 will de-energize
    c. V_4 will decrease conduction, and V_3 will conduct
    d. K_1 will energize, and V_4 will cut off

24. The sweep rate in figure 5-21 is determined by
    a. R_6 and C_6
    b. R_{19} and C_7
    c. C_5 and R_3
    d. C_6 and R_9

25. Coincidence amplifiers are generally
    a. conducting until triggered
    b. single kick multivibrators
    c. in conduction only during the application of simultaneous triggers
    d. triggered with two signals of the same time duration

26. A parasistic reflector should be
    a. longer than a half wave and a half wave from the driven element
    b. longer than a half wave and a quarter wave from the driven element
    c. shorter than a half wave and a half wave from the driven element
    d. shorter than a half wave and a quarter wave from the driven element

27. The radiation pattern of a rotational parabola is directed
    a. at a 45-degree angle
    b. along a wide radiation pattern
    c. along the axis of revolution
    d. perpendicular to a line parallel to the axis of revolution

28. Direct radiation from a parabolic antenna system can be eliminated through the use of
    a. focal point revolution
    b. a slotted parabola
    c. a rotational parabola
    d. a hemispherical shield

29. A slot antenna can be made to radiate from one side of a metal sheet by
    a. boxing in the slot
    b. current feeding at the ends
    c. current feeding at the center
    d. using coaxial feed near the end

30. In a photoelectric cell, the velocity of the emitted electrons depends upon the type of cathode surface and the
    a. wavelength of the incident light
    b. incident light intensity
    c. elements in the anode
    d. positive anode voltage

CHAPTER 6
INTRODUCTION TO MISSILE TESTING

A guided missile is defined as "an unmanned vehicle which moves above the earth's surface in a trajectory or flight path that can be altered by a mechanism within the vehicle." An air-launched missile may be considered as a specialized type of military aircraft in which the functions of the pilot and possibly those of an entire bombing crew are performed by automatic control equipment. In typical missiles, this equipment includes electrical, electronic, hydraulic, pneumatic, and mechanical units, all of which must function perfectly if the missile is to do the job for which it is intended.

To meet the high standards of performance and reliability demanded of guidance and control equipment, the missile must undergo numerous tests at specified times prior to being launched. The rigorous testing required to minimize the possibility of failure underlies one of the major areas in the professional duties of the Aviation Guided Missileman.

Classification of Missile Tests

The numerous tests performed on air-launched missiles can be divided into two major classes: systems and component checkout procedures. The former class includes various processes for evaluating the operational status of the missile as a whole. The latter is made up of procedures for checking the components of the system as independent units.

Systems testing serves to test the total missile for readiness; to reveal any need for adjustment, alinement, or balance; and to isolate malfunctions, if present, to specific components. Among the more important systems checks are those performed on the guidance and control subsystems. Also included are preflight checks made when the missile is on the hangar deck, the flight deck, or when placed on the launcher aboard the aircraft. Component tests are normally made upon equipment packages found to contain malfunctions during systems checkout and are designed to locate defective parts such as resistors, capacitors, or vacuum tubes.

Some form of systems testing is required with all missiles; but not all require component testing—at least not by personnel of missile-expending activities. Those which do not are constructed with packaging techniques so that defective components can be easily removed and replaced with operating components, thereby permitting the defective equipment to be returned to an appropriate shore-based activity for overhaul or repair.

Equipment Requirements in Testing

The test equipment employed by the missileman in systems and component testing includes both specialized test sets and also standard test instruments. A systems test set, which must give a complete and accurate check of the overall operation of the missile, is usually designed specifically for the weapon with which it is used. Some "consolidated" systems testers, however, are in existence which are capable of giving systems checkouts of several different missiles. Component test equipment is highly specialized and contains as typical examples sets designed for testing gyroscopes, batteries, electronic amplifiers, and electrical cables.

SYSTEMS TEST EQUIPMENT

The method of guidance employed in a particular missile determines to a large extent the number and kind of units contained in the systems test set designed to check it. However, there are certain test devices that are common to all systems as well as some units

Table 6-1.—Test equipment required with missiles of various guidance types.

Missile guidance	Hydraulic or pneumatic power	Electric power	Monitor			Motion program	Radar simulator	Info-link	Target simulator
			Power	Guidance System	Wing				
Beam-rider	X	X	X	X	X	X	X		
Command guidance	X	X	X	X	X	X		X	
Active homing	X	X	X	X	X	X			X
Semiactive homing	X	X	X	X	X	X	X		X
Passive homing	X	X	X	X	X	X			X
Inertial guidance	X	X	X	X	X	X			

which are appropriate only for specific missiles. The basic guidance methods applied in air-launched missilery consist of the following: beam-rider, command, and homing. Homing guidance is further subdivided into active, semiactive, and passive. In addition, systems employing inertial guidance methods are being developed, together with the necessary companion test equipment. The essential equipment requirements for testing missiles of these general types are indicated in table 6-1.

The items common to all systems listed in the table are electrical power supplies, fluid supplies (hydraulic and/or pneumatic), programming devices, and monitoring equipment. The differences in equipment result from fundamental differences in the operation of the missile. Beam-rider and semiactive homing weapons, for example, require radar signal simulating units which provide test signals similar to those produced by the radar of the parent aircraft. Missiles of the active- and passive-homing classes require target simulators, which produce test inputs similar to the signals derived from typical targets. Command-guidance missiles require some form of information link between the missile under test and the checkout station to simulate the operation of the aircraft control equipment, which is usually a radio system. Inertial-guidance missiles require no signal simulation equipment unless the inertial units are used in conjunction with another type of system based on radar, infrared techniques, or other methods requiring special input signals for testing purposes.

Typical Systems Test Set

The major components of a typical systems test set are indicated by a block diagram in figure 6-1. The physical appearance of the units is shown in figure 6-2.

The test set is designed for checkout of missiles employing radar homing guidance. The equipment illustrated is capable of providing two types of checks: an overall operational confidence test and various sequences of specific tests for isolating defective operation to a particular component.

The operational confidence test is of short time duration and is based on monitoring the response of the guidance and control sections to inputs that simulate those occurring in flight. The applied test signals include both target simulations and inputs from a motion programmer, the latter serving as an input device in checks of the attitude-control system of the missile. The tests employed to find malfunctioning components are similar in principle to the overall test. The operator selects by means of pushbuttons a certain sequence of tests. These are carried out automatically under control of the programming circuits; appropriate input signals are applied to the stages selected; and the results of each test step appear as visual indication on one of the monitoring units.

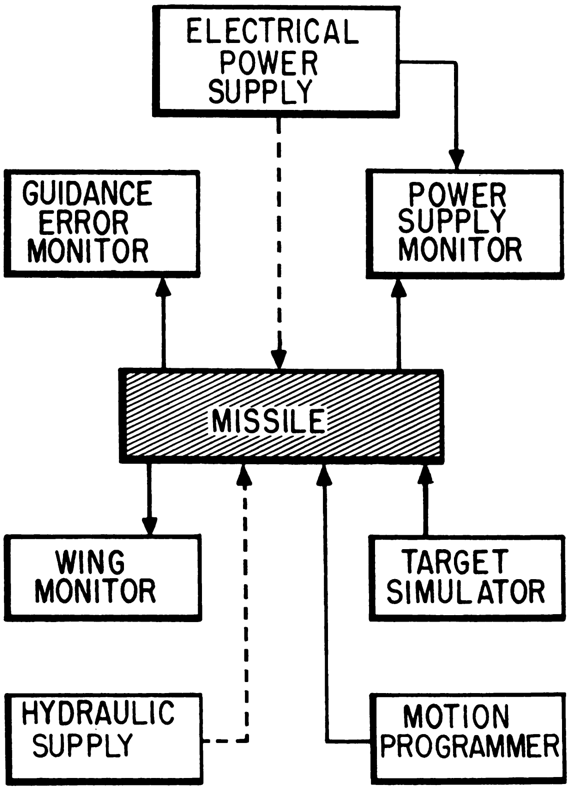


Figure 6-1.—Block diagram of systems test set.

As indicated in figure 6-2, most of the test equipment is mounted in compact consoles to conserve space and to aid in efficiency in checkout. The electrical power supply provides power both for the missile units under test and also for the circuits of the test equipment. The hydraulic supply functions as a source of energy for operating the wing-actuator units, and it also has provision for supplying compressed gas to systems containing accumulators.

By means of the target simulator (fig. 6-2), test signals generated by circuits in one of the consoles are applied to the missile target-seeker antenna. The external units of the simulating device consist of a small horn antenna and an enclosure called an anechoic chamber. The purpose of the latter is to suppress all reflected radiations, thereby insuring that the missile is subjected to signals from only one "target direction." The motion programmer has a twofold purpose: It serves as a test stand to support the missile and also contains motor driven equipment which imparts motion to the missile to simulate rotation about any of the three principal axes.

Three types of monitors are included in the test equipment shown in figure 6-2. The guidance-error monitor evaluates the responses of the missile guidance circuits and displays the test results by visual indications corresponding to accept or reject decisions. The wing-monitor gives indications based on measurements of the wing displacements resulting from applied motion inputs and from servo test input voltages. The power-supply monitor displays the results of checking the voltages supplied the missile units by the test set, and it also monitors certain key voltages produced within the missile. Like the other two monitors, the power-supply unit provides accept-reject indications derived by comparing the output of the circuit under test with standard values representing acceptable conditions.

Automatic Programming and Monitoring

Automatic systems test equipments operate by the accept-reject method and for this reason are usually referred to as GO, NO-GO testers. These test sets eliminate operator opinion as to the state of readiness of the missile and hence carry out tests on an objective basis. They provide rapid and efficient checkout and thus are capable of meeting the demand for high-speed testing and handling.

An example of automatic programming and monitoring equipment is given in figure 6-3, a simplified schematic of GO, NO-GO circuits. The fundamental measurements are made in the comparator circuits indicated here as blocks, but which contain transistorized networks that compare various output voltages with standard potentials. (Examples of comparator circuitry are included in other chapters of the course.) Most test sets of this general type also include a provision for running self-checks of the tester circuits in which voltages supplied to the missile by the test equipment are checked automatically.

After completing a self-check of the test set, the operator initiates the missile test by depressing a start switch. This applies a d-c potential of 28 volts to the lamps L_1 through L_6. At the same time the d-c voltage is applied to the electric motor which is geared down so that it slowly drives a camshaft mounting seven cams (C_1 through C_7).

The cams (fig. 6-3) are arranged so that each operates a switch which is held closed for a certain time and then opened. As the

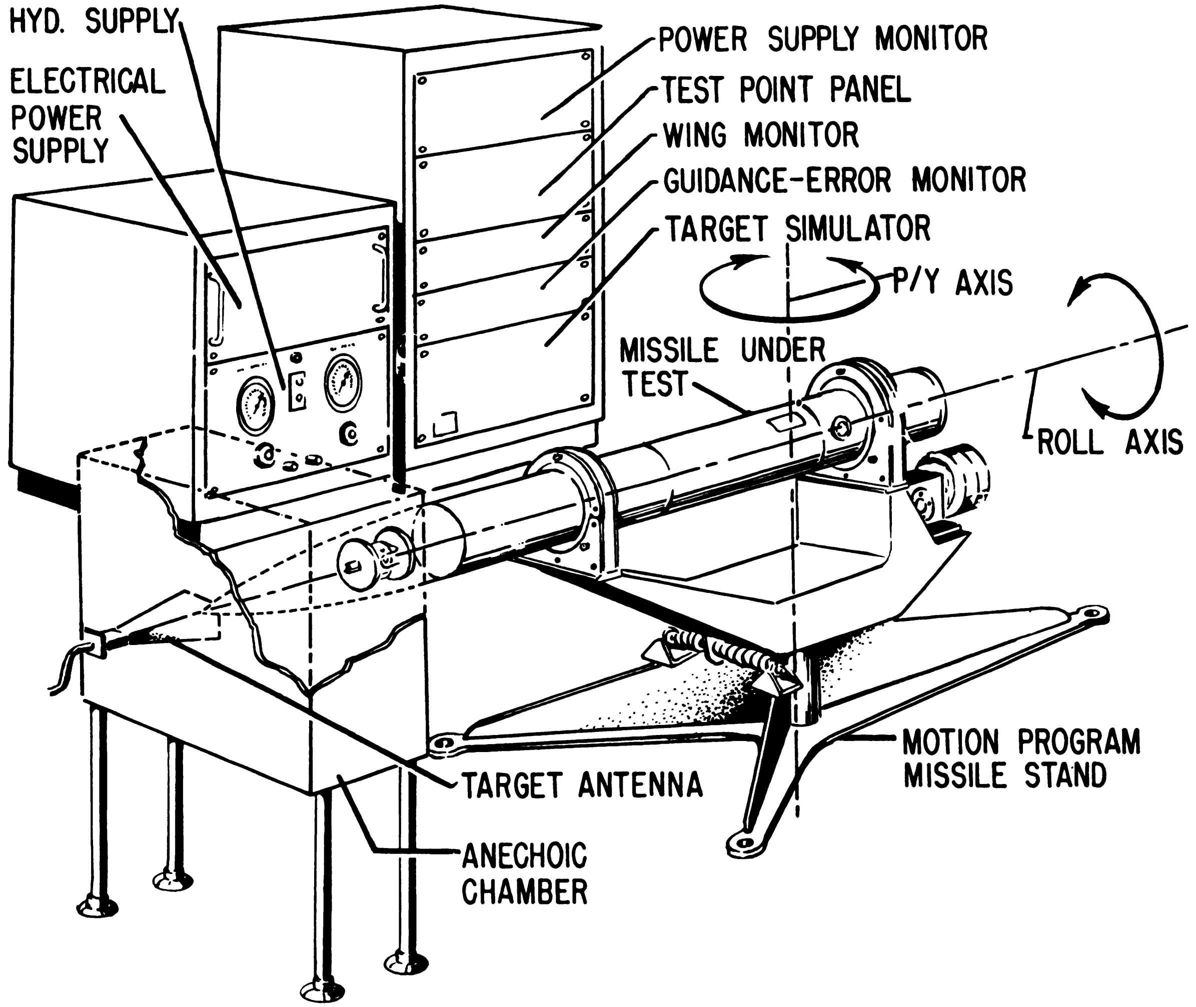


Figure 6-2.—Systems test equipment.

camshaft rotates, the switches are thus opened and closed in sequence. When cam C_1, for example, closes switch S_1, the B-plus voltage from the missile power supply is applied to one of the comparator circuits where it is compared with a standard voltage. If the missile voltage is equal to the standard, or if it differs from it by an amount within the specified tolerance limits, relay RL_1 is energized and voltage is removed from lamp L_1, causing it to be extinguished. (Elements RL_1 through RL_6 are latching relays which have the property of remaining in the energized position even though the energizing voltage is removed. They can be unlatched by separately energized auxiliary coils not shown in the drawing.)

The circuits are tested in sequence under control of the rotating camshaft; and as each is found to be acceptable, a relay is energized and the corresponding lamp is extinguished. If the entire group of checks show in-tolerance results, the six relays RL_1 through RL_6 are all energized to complete the circuit which illuminates the GO lamp, thereby indicating a satisfactory test sequence. If any particular step produces an out-of-tolerance result, the associated relay fails to energize, the lamp controlled by it remains lighted, and when switch S_7 is operated at the end of the sequence, the NO-GO lamp comes on.

In this manner, the missile circuits are checked with great accuracy, provided, of course, that the test equipment has been properly set up. An important feature of the method is that errors of judgment are largely eliminated. The comparison procedure removes the possibility of errors resulting from parallax in reading meters as well as human errors

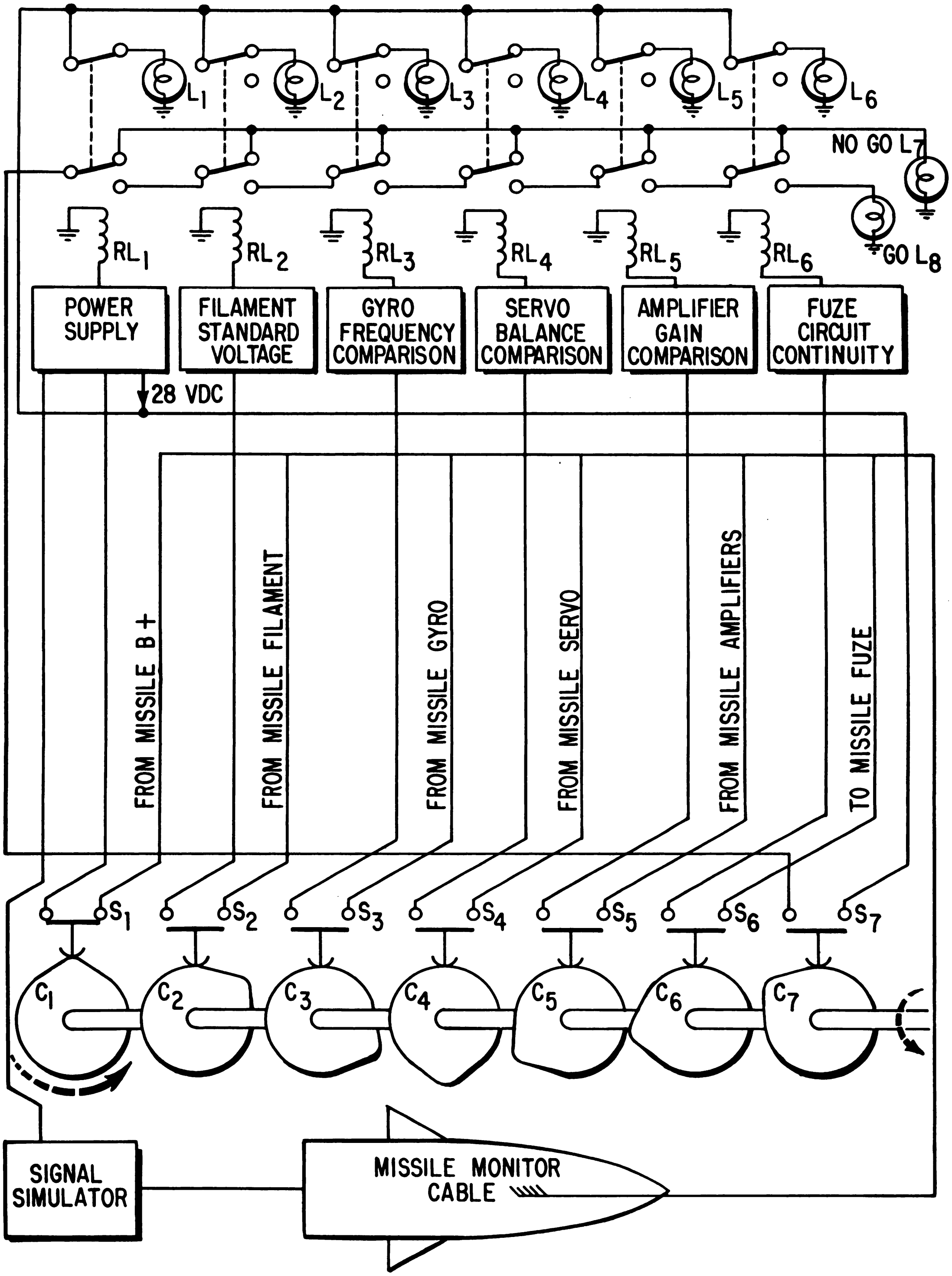


Figure 6-3.—Simplified schematic of GO, NO-GO equipment.

affecting decisions as to whether a given voltage is in or out of tolerance. Test sets operating on these general principles are available in compact form with the entire equipment mounted on wheels for easy access to missile units in stowage compartments and other areas where space is limited.

Preflight Checks

Most of the procedures of systems testing involve checkout of the missile guidance and control sections. When these have been subjected to all the required checks and evaluated as fit-to-fly, the missile is assembled in final form and made ready for preflight tests.

The majority of preflight tests are performed prior to attaching the missile to the aircraft launcher. On aircraft carriers, these checks are made when the missile is either on the hangar deck or on the flight deck. The particular procedures vary widely with different missiles but usually include the following:

1. Continuity checks to insure proper electrical mating of all assembled sections.

2. T-R tuning. This is necessary in some beam-rider and semiactive radar missiles to be sure that the T-R tubes are tuned to the frequency of the aircraft radar.

3. De-arming checks, which in most cases are visual in nature, consisting of inspection of the arming devices to see that the ordnance units are in the safe, or de-armed condition.

4. Launcher checks. The aircraft launchers are checked to eliminate all possibility of accidental detonation of missile warheads and fuzes or premature ignition of the rocket motors. The required checks are usually for continuity and for the presence of stray voltage.

Final preflight checks are accomplished after the missile is secured to the launcher. As a rule, these checks require no test equipment but are accomplished by means of the electronic equipment of the launching aircraft. The purpose of final preflight testing is to establish operational readiness of the complete system by checking the functioning of the aircraft units in combination with the associated missile.

Component Testing

With some missile systems, component testing is an essential part of the missileman's duties, while with others, it forms no part of the total test program. The decision to test or not to test on a component basis, which is made in the early stages of missile planning, is influenced by many factors. Among these are the cost of developing and procuring special test equipment, the additional training time required to familiarize missile personnel with its use, and many other problems of logistics and supply.

Missile systems that require component testing have certain advantages for the missileman with regard to repair, maintenance, and modification. In these missiles, the equipment is packaged in plug-in assemblies, each of which can be removed easily and replaced with a similar assembly. This enables the missileman to make rapid repairs in malfunctioning systems by simple substitution methods. The defective components can then be checked as independent units or else returned to a shore-based activity for overhaul or extensive repair. This type of packaging also facilitates handling since typical component packages are relatively small and easy to stow and their use minimizes the number of cumbersome and heavy sections. The components in most cases are constructed so that individual parts such as resistors, tubes, and capacitors are readily accessible for replacement or change, which is advantageous when making necessary modifications in operational equipment.

EQUIPMENT REQUIREMENTS IN COMPONENT TESTING

One of the essential requirements of component-test equipment is accuracy and precision of measurement. A particular component, which functions as one of many units of a complex system, must meet tolerance requirements that are much closer than those of the total system of which it is a part. The results of slight malfunction in any one stage are multiplied and build up in magnitude as the signal proceeds through the system. Thus, an out-of-tolerance output voltage of an amplifier operating as one of the initial stages of a control channel may result in a total overall discrepancy that exceeds the limits of acceptable channel performance.

Component testing requires extensive technical knowledge and skill on the part of the missileman since it involves the use of many types of test equipment. He uses specialized test sets designed for exclusive application to specific components, standard Navy test instruments, and general-purpose devices not readily available through Navy supply channels. Standard instruments in common use include items such as precision voltmeters, oscilloscopes, crystal checkers, and other instruments used in the general field of electrical and electronic work. A complete list of available standard test instruments is given in the publication *Aeronautical Electronics Test Equipment*, NavAer 00-35QR-5. A representative example of a specialized test unit is given in the following pages.

Testing Missile Amplifiers

A typical setup for testing a missile amplifier unit is illustrated in figure 6-4. The following facilities are provided:

1. D-c supply voltages which correspond to those normally fed to the amplifier while in the prime equipment and which render it operative for test purposes.

2. A-c signal voltages controllable in amplitude by the operator and which simulate the control information fed to the amplifier unit in actual operation.

3. Provision for feeding the output of the amplifier unit into the test set for evaluation and comparison with required output values.

The specialized test set and power supply are shown in figure 6-5. The former contains circuits which generate the signals that simulate normal amplifier inputs and also provide a means of measuring the outputs resulting from these applied voltages. The power-supply unit produces the d-c potentials required both in the amplifier under test and in the test set. Associated test instruments used in the check procedure include a d-c filament supply, a vacuum-tube voltmeter and an oscilloscope.

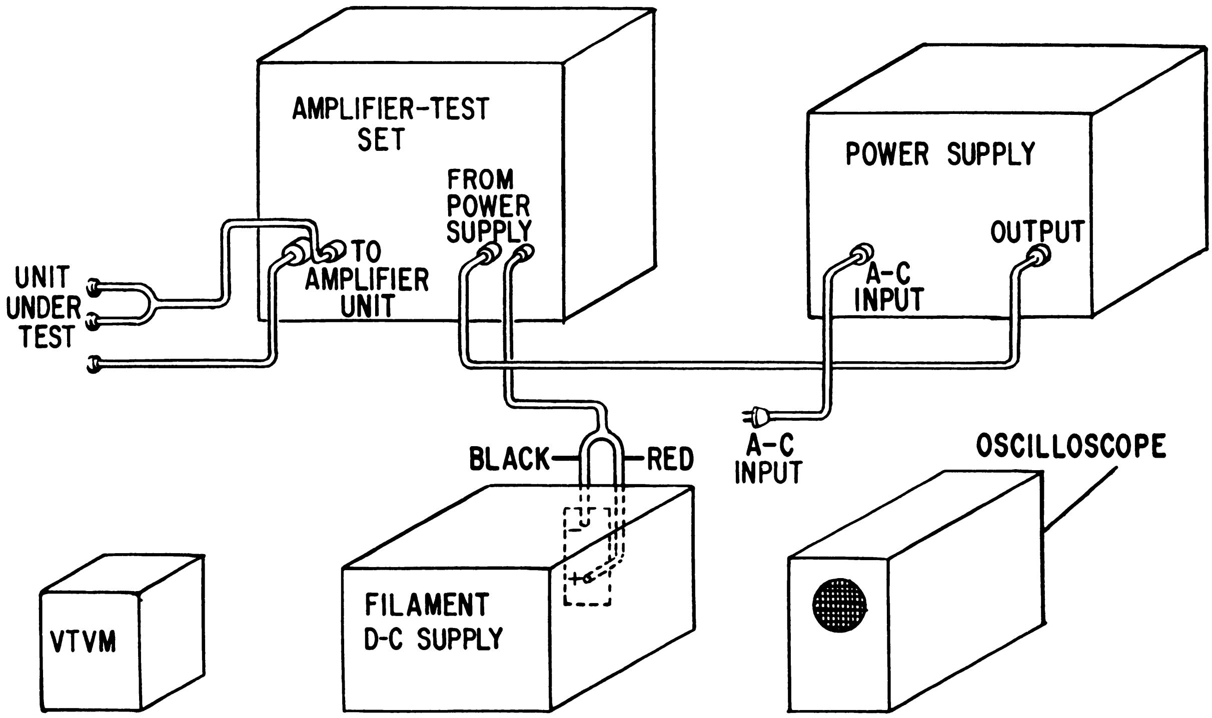


Figure 6-4.—Typical setup for component testing.

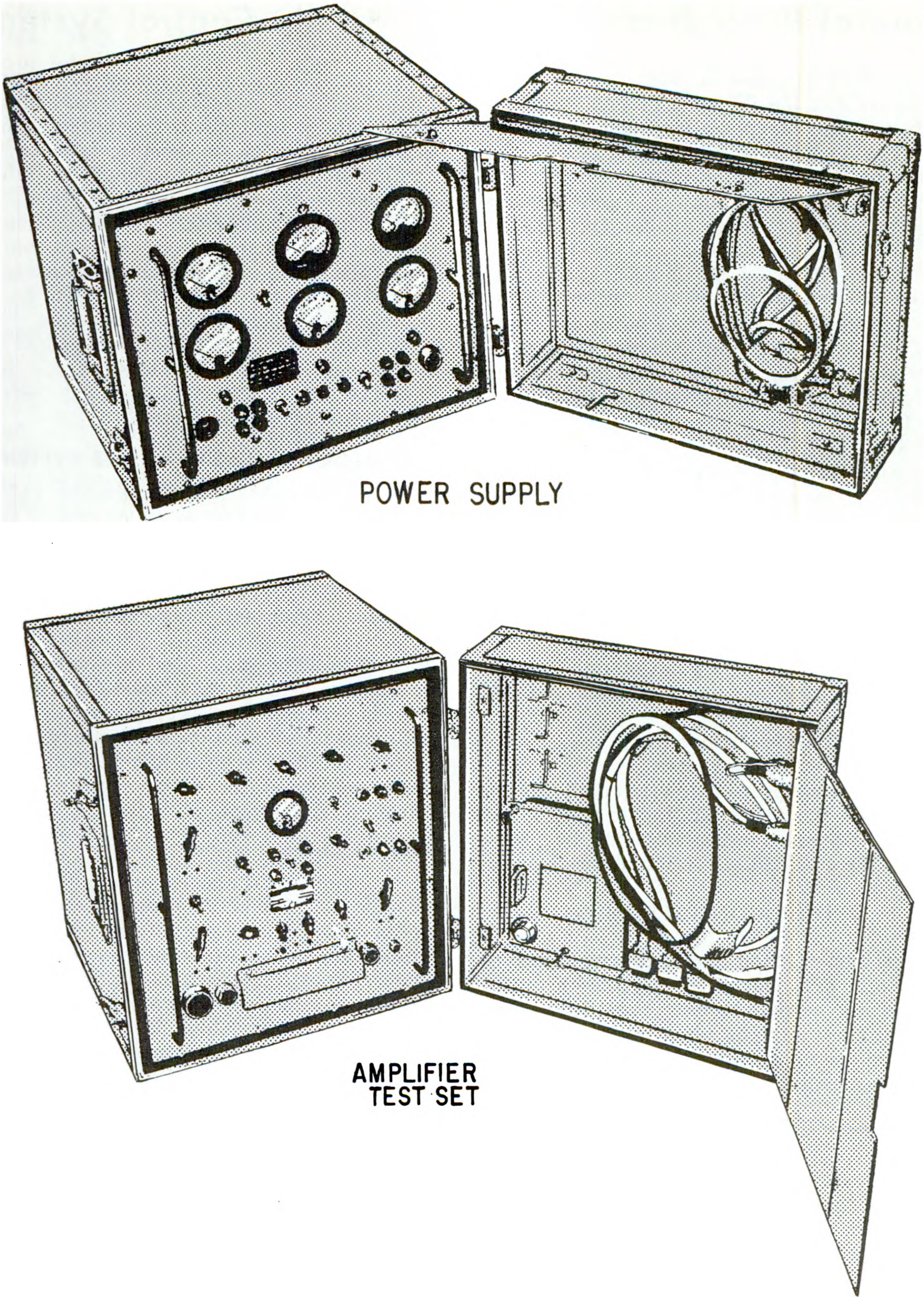


Figure 6-5.—Amplifier test set and power supply.

General Procedures in Testing Missile Control Systems

To be well qualified for systems and component checkout, the GF must be proficient not only in the use of specialized test equipment but must also be able to perform many tests that cannot be accomplished by automatic devices. Skill in testing requires a good working knowledge of the missile together with an adequate fund of general technical information. The missileman must be thoroughly familiar with the authorized checkout procedures given in the appropriate missile handbooks and must follow these instructions in detail. He must be adept in the use of basic test instruments and skilled in applying certain general procedures that are required in most types of missile tests.

Because of the variety of air-launched missiles, it is not possible to describe all procedures employed; however, the following are sufficiently fundamental to be valid in most cases.

1. Physical inspection.
2. Checks on components of power-supply systems.
3. Electrical point-to-point tests.
4. Zeroing and balancing checks and adjustments.
5. Servo static-response tests.
6. Dynamic-response tests.

The first four procedures listed above are described in the following pages; static- and dynamic-response testing methods are discussed in the concluding section of the chapter.

PHYSICAL INSPECTION

Visual inspection of the equipment is one of the essential procedures required in checkout. The operator should remain constantly alert to detect any sign of physical defect since many components test satisfactorily even when containing faults that cause failure during flight. The following list contains examples of visual checks usually made during systems testing:

1. Insulation and conductors are inspected to insure that neither is broken, frayed, or otherwise defective.
2. Plugs are checked for good contact when fitted in jacks.
3. Vacuum tubes are inspected for security of mounting and the suspensions of electronic chassis are checked for security.
4. Cables and rubber tubing are examined for presence of cuts, breaks, or deterioration.
5. Rotary equipment is checked for the presence of worn or binding brushes, dirty commutators, and for evidence of defective bearings.
6. Inspect equipment for the presence of dirt and corrosion.
7. The gyros are inspected to insure that they are properly caged (or uncaged) as specified in the authorized test procedure.
8. Switches are checked for proper positions, and relays are inspected for burned contacts or for any condition that results in restriction of normal motion.

CHECKING MISSILE POWER SYSTEMS

The term missile power system refers to all the equipment that provides energy for the guidance and control units including electronic, electrical, hydraulic, and/or pneumatic devices. The power system is normally checked prior to running tests of the control units since the latter cannot function properly unless the applied voltages and fluid pressures are at correct values. In addition to the automatic checks performed by systems testers, checkout procedures often include battery and cable tests, generator checks, and inspection of the fluid apparatus for correct pressures and freedom from leaks.

Battery Checks

In some air-launched missiles, batteries provide the primary source of electrical power. The batteries are activated by methods which vary widely, depending upon the battery type. Checks are then made of the voltage regulation, and the general condition of the associated power cables is tested by indirect methods. Voltages are measured under load conditions both at the battery terminals and at the load ends of the cables. The battery voltage can then be compared with the rated full-load value; and high-resistance connections or other cable defects can be detected by the presence of abnormally low voltage readings at the load.

Generator Checks

The missile test equipment provides the primary power for operating the generators

during checkout. Missile generators are of various types but most are equipped with voltage regulators to hold the output constant with changing load conditions. The fundamental check consists of measuring the generator voltage under full load to determine the voltage regulation as in the case of the battery check.

Filling Reservoirs and Bleeding Systems

Prior to checkout of the fluid system, the hydraulic reservoirs or accumulators are filled according to authorized procedures. These usually contain miscellaneous precautions as to cleanliness, proper types of fluids, and the amounts of torque to be applied when tightening threaded fittings. Bleeding the system is the process of ridding it of air bubbles and is normally accomplished with the aid of special test devices.

Pressure Tests

After the fluid system has been charged, it is first inspected to see that pressure is maintained within the prescribed limits. The gages situated at various points in the system are checked to insure that the pressure regulators are in correct adjustment and are functioning properly.

Leakage Tests

The presence of leaks is indicated principally by the inability of the system to maintain pressure over a period of time. The units are usually subjected to greater-than-normal pressure during checkout to provide a margin of safety which aids in assuring dependable operation. Under high pressure, leaks in hydraulic lines or at fittings can be found by simple visual inspection; while those in pneumatic systems can be detected by applying a soap solution at probable trouble spots.

ELECTRICAL CHECKS

Many electrical point-to-point checks are made on control equipment by measuring continuity in cables and through relay contacts and by measuring voltage at certain points in the system specified in the authorized test procedures. These measurements are made both by automatic processes and by means of ohmmeters, meggers, and voltmeters.

When checking relays by the continuity method, contacts are seldom tested individually; rather the measurements are made on series circuits made up of many normally closed contacts contained in a number of relays. In continuity checks conducted by machine methods, the circuits under test complete current paths to indicator lamps, which indicate when lighted that all contacts within a particular circuit are making properly.

Among the missile voltages frequently checked are supply potentials, input and output voltages of amplifiers, and the d-c potentials applied to the plate, grid, or cathode circuits of electron tubes. A number of checks are required on miscellaneous items such as arming, destruction, firing circuits and on parts of the command control circuit. In most cases, these circuits are tested by simple continuity measurements.

ZEROING AND BALANCING

Before the missile can be given an overall operational test, certain control units must be checked for zero or balance and the appropriate adjustments made. Tests for balance of the wing actuators and controllers are usually made by the operator as a preliminary step in checkout of the fluid system. He inspects the pistons of the wing actuators to insure that they do not creep off mid-position under no-signal conditions and checks the spool valves for freedom of movement on either side of the center position.

Zeroing and balancing adjustments are required on many servo amplifiers, the pickoffs of motion-sensing instruments and transducers, and on synchros when these are present in the system tested. Many servo amplifiers are double-ended circuits that produce balanced outputs similar to those of a push-pull power amplifier. A circuit of this type is checked for equality of gain in the two tubes, and manual adjustments are made to compensate for lack of balance. In some cases, the d-c plate currents of the balanced amplifier are included in the output, and these must be adjusted to equality under no-signal conditions.

Pickoffs of gyroscopes are usually zeroed by the manufacturer but are normally checked prior to testing. Other pickoffs to be checked are those of accelerometers, feedback potentiometers in the wing-servo circuits, and the transducers of telemetering equipment if employed in the missile. A task closely allied to zeroing of pickoffs is that of checking them for linearity. This consists of determining whether the output of the instrument is proportional to the displacement of the movable element.

Synchros are zeroed by adjusting them for null output when the rotors are set at certain built-in reference marks which correspond to electrical zero.

Servo Response Tests

It is one of the normal preflight duties of every pilot to operate the controls of his aircraft to be sure they respond correctly. Similar tests are required with guided missiles to insure dependability in flight. In missile systems, the functions of the pilot are carried out by automatic equipment, which includes, in typical weapons, the units shown in figure 6-6. Since the missile is essentially a "one shot" weapon and cannot be test flown, the next best thing is to measure its responses to inputs which simulate the conditions of actual flight. In general, the procedures used in testing guidance and control subsystems and their components are of two basic types: static-response and dynamic-response checks.

STATIC-RESPONSE CHECKS

Static checks are made on servo units by applying constant inputs and by measuring the results at the output without regard to the time required for the system to respond. With some missiles, test sets designed for this type of check are used for testing attitude-control channels and motion-sensing instruments. Static tests are also frequently employed for systems checkout of missiles with comparatively simple guidance equipment. Consider as an example the procedures often used in checking the pitch or yaw control channels shown in figure 6-6. The checkout may be conducted in one of several ways, all of which involve application of inputs simulating missile motion.

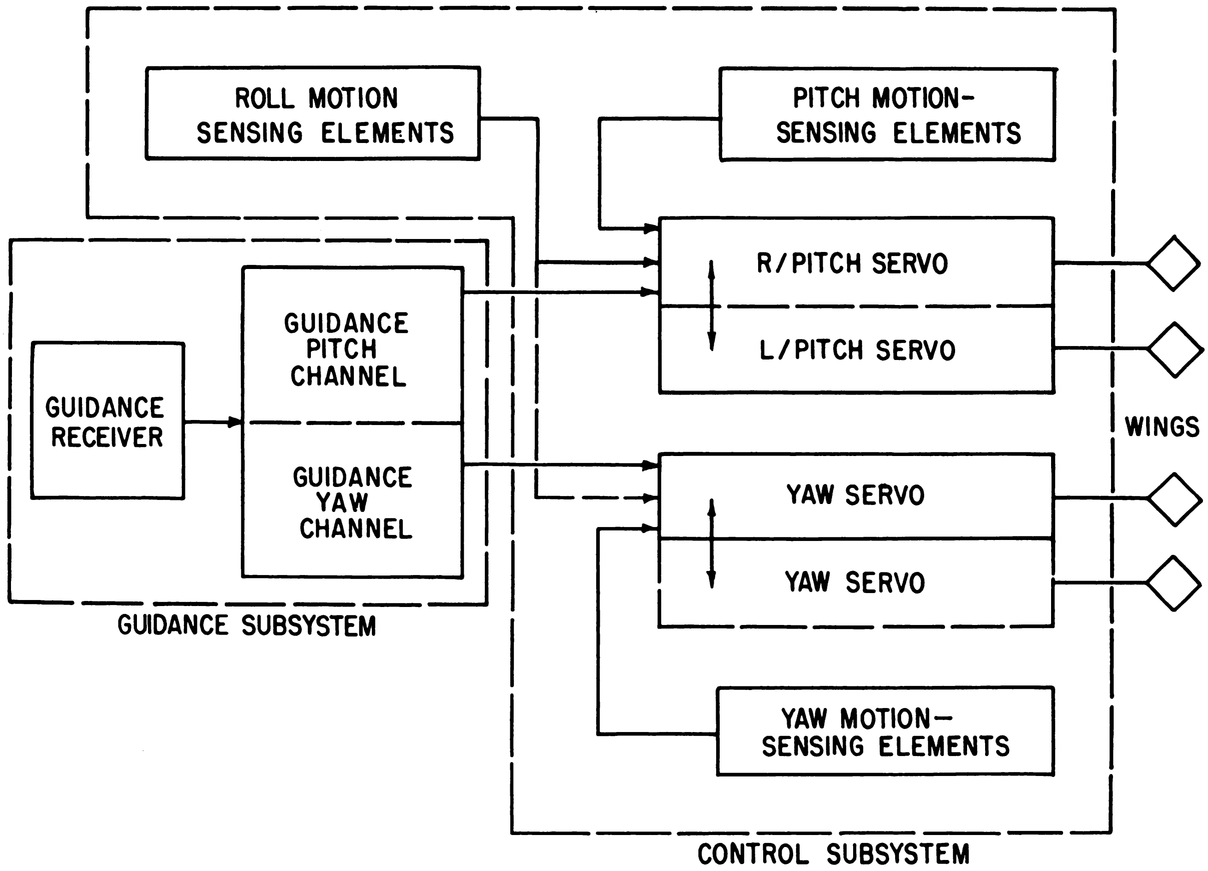


Figure 6-6.—Block diagram of typical guidance and control equipment.

If the missile is small, it may be mounted on a specially designed tilt stand which adjusts the missile position to vary the attitude through various conditions. Assume that the pitch channel is being checked. The missile is tilted to a nose-up attitude with an angular position specified by the checkout instructions. The motion-sensing instruments affected produce error signals. These cause the control units to apply corrective action by adjusting the wings, which move through a certain angle and remain there as long as the error voltage is present.

With the particular attitude error simulated, the angle of the control-surface displacement is then measured to see that it is within the acceptable range of values corresponding to this input condition. Out-of-tolerance displacements in this type of test indicate the possibility of instability in flight. Overcontrol, if present, causes the missile to overshoot the desired flight path and to oscillate about it; if the wing response is too slight, the missile would deviate too far before the corrective action is sufficiently great to return it to the desired attitude. After checking in the nose-up attitude, the missile is then placed in a nose-down position with an equal angular displacement, thereby reversing the sense of the error signal. The wing responses should be equal (plus-or-minus a specified amount) for both types of input conditions. After completing the required checks on the pitch channel, the other attitude-control units are tested in similar ways.

Attitude static response is also measured by a second general method, particularly if the missile section is physically large. The motion-sensing instruments are tested separately by placing them on a small gyro tilt stand which introduces motion about any of the sensitive axes. Electrical connections are made to connect the instruments to the source of required energy and the table is tilted to simulate changes in missile attitude. The outputs of the motion-sensing instruments are then measured and compared with standard values.

A third general procedure in attitude testing is sometimes applied in which artificial error voltages are generated in the test equipment and applied to the stages following the motion-sensing instruments. The reaction of the missile control surfaces is then measured and the ratio of angular deviation to input voltage is determined. This ratio is the gain of the control stages under test and serves as a convenient measure of their performance. A disadvantage of this method of attitude testing lies in the fact that the gyros and accelerometers are not checked in the process and must be tested separately to give a complete checkout of the wing-control units. The signals injected to simulate the normal outputs of the motion-sensing instruments are usually a-c voltages which can be varied by the operator in phase and in amplitude. By reversing the phase of a particular signal, a reversal in the sense of the simulated error is made.

Static-response checks are often employed for testing control systems in which the corrective motions made by the wings are not proportional in amplitude to the amount of error present. An example is any missile with bang-bang control. In this system, the control units operate as an open-loop servomechanism and steering is accomplished by means of wing actions that are either zero or maximum deflections. Missiles of this type are given systems tests at the factory and many require no field testing. With those that do require tests by expending activities, the necessary checks usually consist of static-response measurements made on components such as wing actuators, transfer valves, or electrical controllers.

In more complex missiles, the results of static testing give only a partial indication of system or component performance, and more elaborate checkout procedures are required in which the response of the units to changing errors is determined.

DYNAMIC-RESPONSE CHECKS

In dynamic-response checks, the missile system is subjected to changing input signals so that the time lags present are taken into account. A series of changing input conditions are simulated by means of error voltages that vary in frequency, phase, and/or amplitude and the resulting wing deflections are either compared with standard values or else are recorded for later analysis. Dynamic checks, which are capable of testing the full range of missile performance, are made for two basic reasons:

1. To test the reaction of the system to error signals that vary at rates possible in flight.

2. To determine whether the response meets the requirements of stability.

The first of these checks is based on the fact that proper wing response to a constant error does not guarantee that the results will be similar with changing errors. Since there are time lags present in the action of the system, the speed of response is a factor of primary importance. In general, not only must the control surface move in the proper sense and by the proper amount; it must also move at the proper time.

Excessive time delays are a principal cause of instability in closed-loop servo systems. Sustained oscillations are developed when the total time lag of the system is sufficiently great that the system corrects for past errors when subsequent errors are present in the input. In missile equipment, the total lag is a resultant of many small delays contributed by various units of the system. The following are the principal sources of time lag in most missiles:

1. Slack, bending, and expansion in mechanical linkages.
2. Expansion and contraction of hydraulic lines.
3. Lags resulting from the compressibility of air in pneumatic units.
4. Phase lags in electrical and electronic equipment.

Transient and Sinusoidal Response Checks

Basically, there are two methods of determining the dynamic response of servo control systems or components. The first is by study of transient action of the device following a change in the input; the second is by measurement of the response of the device to sine-wave inputs. The latter type of test is essentially a frequency-response check.

Transient tests are made principally to check the system for stability in operation. A typical procedure is to apply a step-function input (as indicated in (A) in fig. 6-7) and to evaluate the response by measuring the time interval required for the system to reach the final, or steady-state, condition.

The general types of possible response to the step-input voltage are shown in (B) of figure 6-7. If the degree of damping in the system is insufficient, the output member of the system will oscillate continuously as indicated in curve d. With a different damping factor, the output approaches the final condition in a very slow rise, as shown in curve a. Systems with this type of response are said to be overdamped. In curve b, the system response is such that the final state is attained in the minimum time without overshooting, which is characteristic of critical damping. If the response is similar to that in curve c, the system is said to be underdamped. In most cases, the desirable degree of damping is such that the response is somewhere between the actions illustrated in curves b and c, although ideal response in a particular device is determined largely by the specific application.

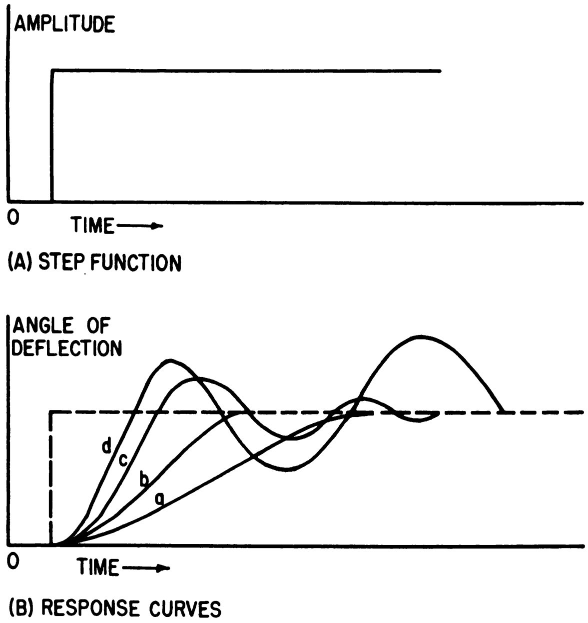


Figure 6-7.—Possible responses to step-function input.

In its basic form, the sinusoidal dynamic test provides a frequency response check of the servo system. The applied signals are sine waves of constant amplitude which vary in frequency over a certain range. The output of the system then consists of sine-wave variations, which can be compared with the input both in amplitude and in phase. The output of an ideal servomechanism would be proportional in amplitude to the input with a constant phase displacement for each frequency. While no physical system has this ideal response, the requirements of practical equipment can be met if the response approximates the ideal condition over the appropriate frequency range.

Error-Signal Simulation

Figure 6-8 shows a type of sine-wave signal often used for testing missile control units

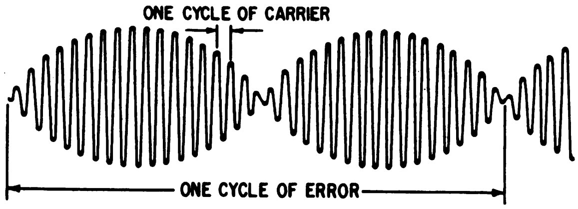


Figure 6-8.—Simulated error signal for dynamic testing.

designed for response to a-c error signals. In these systems, the error information appears as a low-frequency variation of an a-c carrier wave. This type of input is simulated in typical test sets by various methods, one of which is by use of a synchro generator. The rotor is revolved at a rate equal to that at which it is desired to deflect the missile wings. A constant a-c voltage is applied to the stator at a frequency equal to the simulated servo carrier wave. Under these conditions, the resulting output is of the form illustrated in the figure. By varying the rate of rotation of the synchro rotor, the modulating component of the test signal can be varied to provide the desired range of servo test frequencies.

Other methods of simulating a-c errors involve the use of low-frequency signal generators and mechanically driven rate tables which apply motion inputs in the form of sine-wave variations.

Dynamic frequency-response checks are particularly effective for checkout of systems in which compensation must be made for natural resonance effects, particularly when the control units respond to a-c servo signals. A typical example is a beam-rider missile in which the guidance information is provided by a pulse modulated radar beam. The error information is impressed on the carrier as a result of the missile's deviations from beam center; and during corrective action by the missile, this information is converted in the radar receiver to voltage pulses which vary in amplitude at rates from zero to about ten cycles per second.

Because of its weight, shape, and airframe characteristics, the missile has a natural resonant frequency at which oscillations about the flight path tend to build up in magnitude. This natural frequency lies within the range of servo control frequencies employed in the system; and hence, the control section must be compensated so that error signals at the natural frequency of resonance do not result in excessive oscillation and loss of control.

Lead and Lag Networks

In many missiles, the required shapes of the servo response curves are obtained by the use of lead and/or lag networks. Lead circuits attenuate signals in the low-frequency region of the band and pass higher frequencies with little loss. At the same time, they introduce phase leads (positive phase shifts) in low-frequency signals. Lag circuits, on the other hand, attenuate the highs and middle-highs and simultaneously cause phase lags (or negative phase shifts) of high-frequency signals. These networks, which are specialized filters, are usually composed of combinations of resistance and capacitance.

A typical servo phase network is shown in figure 6-9. With appropriate values of R and C, the frequency-phase response is that represented in the two curves. This network is characteristic of the type employed in missiles with a range of servo frequencies approximately equal to that of the beam-rider weapon described above and in which the resonant frequency of the overall system must be attenuated to prevent overcontrol. Note that the circuit minimizes output-signal amplitude when the error frequency is 0.2 c.p.s., the resonant frequency of the missile; also, the phase displacement at this frequency is comparatively small.

Measuring and Analyzing Test Results

After application of input voltages that simulate changing error signals, the final job in dynamic testing is analysis of the output. In most cases, the control surfaces constitute the output device so that wing deflections serve as primary data. A method often used to collect the output data is based on the use of pickoffs connected to the wing-actuator linkages. The pickoff develops electrical signals that vary in amplitude and polarity with the angular deflection and direction of the linkage, thereby providing output data in a form that can be conveniently compared with the input signals.

Phase leads or lags are often measured by means of two pen recorders connected so that one records the input and the other reproduces the output variations. The resulting graphs, when calibrated in terms of time versus voltage, indicate the phase displacements produced by the units under test.

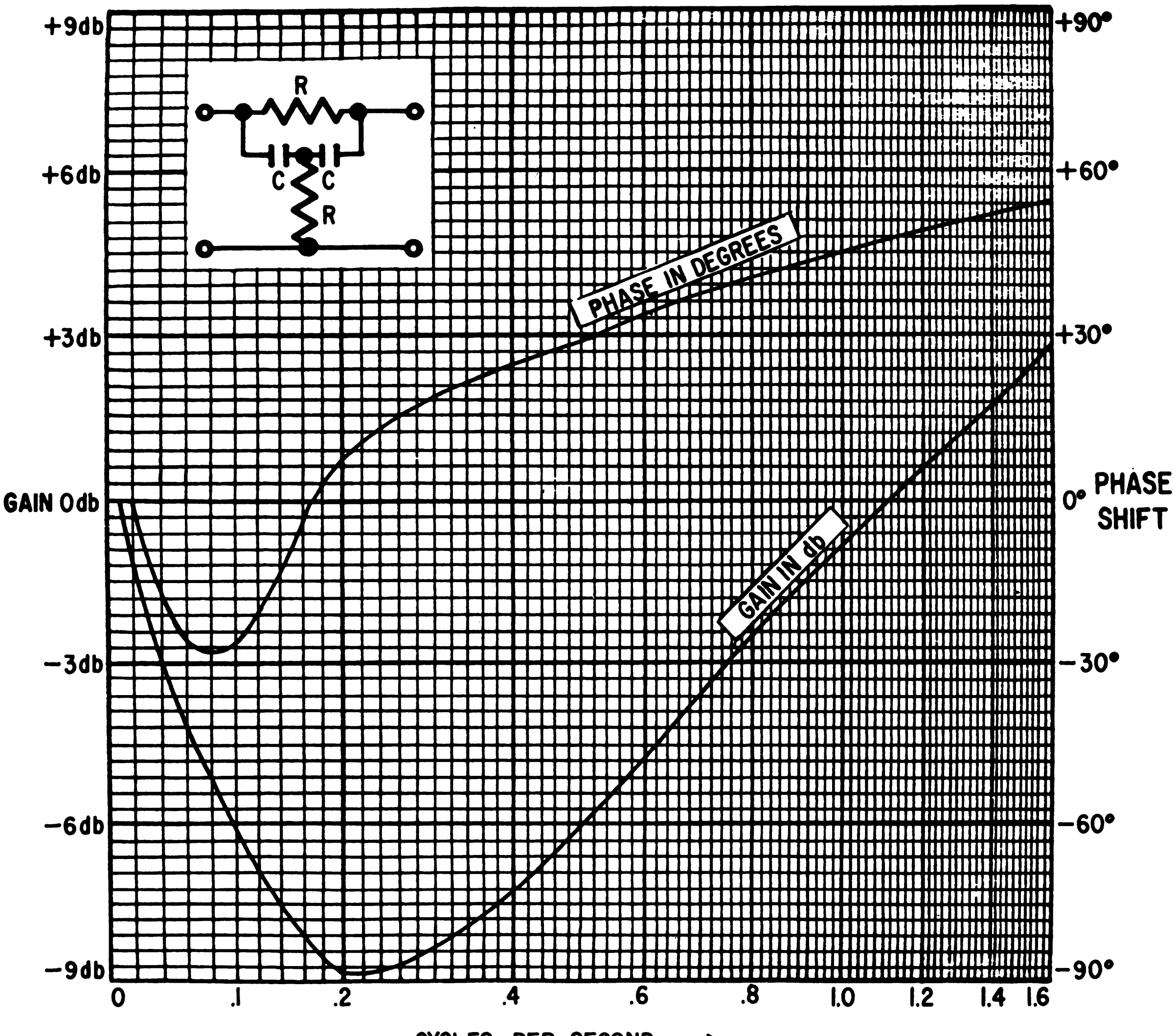


Figure 6-9.—Lead-lag network and response curves.

In addition to graphical recording, the following methods are also used in evaluating test results:

1. Visual inspection of oscilloscope screens.

2. Visual reading of meters connected in special phase comparator circuits.

3. Analysis of the test results as recorded by photo-oscillography.

A complete analysis of the dynamic characteristics of a system or component requires that tests be run at many frequencies; however, for most practical purposes, three or four well-chosen input frequencies are sufficient to provide the necessary information. Dynamic-response checks are usually performed as the final checks of a series of test procedures. They provide the most rigorous and decisive tests possible and produce maximum amounts of information concerning the capabilities of the system.

The discussion of the various types of response tests in the foregoing pages is general in nature and no attempt has been made to deal with specific equipment. The chapters which follow are concerned with more detailed aspects of testing, with circuitry of test equipment, and with the troubleshooting and repair techniques employed by the missileman.

QUIZ

1. Missile plug-in packages are usually
   a. removed and replaced by use of power screwdrivers
   b. tested without the use of standard electronic test equipment
   c. returned to shore based activities for overhaul
   d. cumbersome and heavy

2. A missile test set will normally
   a. simulate inputs and provide a means of measuring the outputs
   b. have self-contained automatic calibrating devices
   c. have no self-contained d-c power supplies
   d. require no additional test instruments

3. An important part of a missileman's duties includes
   a. component testing
   b. design of special missile circuits
   c. calibration of the aircraft's guidance radar
   d. design of missile power supplies

4. Missile plug-in packages are usually constructed so that
   a. parts are readily accessible for replacement
   b. the entire package must be replaced due to malfunction
   c. all missile packages are interchangeable
   d. all packages in the missile are uniform in shape and size

5. In most cases, missile arming, destruct, and firing circuits are toasted by
   a. simple continuity measurements
   b. measuring voltages at certain points in the system
   c. completely automatic processes
   d. using a standard model "megger"

6. The fundamental check of a missile generator consists of
   a. measuring the generator under full load
   b. measuring the generator under no load
   c. checking for worn or binding brushes
   d. checking for evidence of defective bearings

7. An active homing missile does not normally require test equipment incorporating a
   a. radar simulator
   b. target simulator
   c. monitor
   d. hydraulic or pneumatic power

8. In figure 6-7 (B), critical damping is indicated by response curve
   a. b
   b. a
   c. c
   d. c

9. The motion-programmer serves as a test stand to support the missile and serves as an input device in checks of the missile's
   a. attitude-control system
   b. target seeker
   c. thrust accelerometer
   d. power supply

10. Most automatic systems test sets usually include a privision for
    a. performing self checks on the tester circuits
    b. isolating individual malfunctioning parts
    c. checking out-of-tolerance voltages
    d. connecting auxiliary test equipment

11. The required shapes of the missile servo response curves may be obtained by using
    a. R-C circuits
    b. low frequencies
    c. high frequencies
    d. F-M inputs

12. Complete analysis of the dynamic characteristics of a missile system requires that tests be run at
    a. many frequencies
    b. four frequencies
    c. one frequency
    d. missile resonant frequencies

13. Component test sets are employed in checking
    a. complete missile response to simulated flight conditions
    b. for proper missile assembly
    c. defective components as independent units
    d. electrical continuity after final assembly of the missile

14. The term "missile power system" refers to
    a. electronic equipment only
    b. hydraulic equipment only
    c. electric and electronic equipment only
    d. all the equipment that provides energy for the guidance and control units

15. To provide a margin of safety which aids in assuring dependable operation of the missile hydraulic system, the units are
    a. first inspected to see that pressure is maintained within prescribed limits
    b. subjected to greater than normal pressure during checkout
    c. checked under high pressure, and leaks detected by applying a soap solution at probable trouble spots
    d. checked to insure that pressure regulators are in correct adjustment

16. Static response checks are made on servo units by applying
    a. variable inputs and measuring the results at the output with regard to time required for system response
    b. constant inputs and measuring the results at the output without regard to time required for system response
    c. constant inputs and measuring the results at the output with regard to time required for system response
    d. variable inputs and measuring the results at the output without regard to time required for system response

17. After application of input voltages that simulate changing error signals, the final job in dynamic testing of a missile is
    a. analysis of the output
    b. collecting the output data
    c. checking switches for proper setting
    d. static testing for comparison

18. The purpose of a missile guidance final preflight test is to
    a. establish operational readiness of the aircraft and missile systems
    b. establish operational readiness of the missile only
    c. eliminate accidental detonation of the missile warhead and fuze
    d. eliminate accidental or premature ignition of the rocket motor

19. Final preflight checks on air-launched guided missiles are accomplished
    a. after the missile is secured to the launcher
    b. during the missile system test check
    c. during the missile component test check
    d. prior to securing missile on the launcher

20. Go, No-Go testers operate by the accept-reject method and are advantageous in that they
    a. eliminate operator opinion as to missile readiness
    b. eliminate preflight tests
    c. eliminate the necessity of component testing
    d. eliminate launcher checks

21. Tests performed on air-launched missiles are divided into two major classes which include
    a. systems and component tests
    b. systems and preflight tests
    c. component and automatic programming tests
    d. preflight and automatic programming tests

22. Equipment required to test a missile utilizing inertial guidance includes a
    a. programming device and monitoring equipment
    b. radar simulator and a programming device
    c. information link and a radar simulator
    d. target simulator and monitoring equipment

23. Missile radar signal simulating units are required to test
    a. beam-rider and semiactive homing weapons
    b. beam-rider and active homing weapons
    c. active and passive homing weapons
    d. active and inertial homing weapons

24. During the static-response check, the wing position voltage will be greatest when the error voltage input is
    a. out of phase
    b. in phase
    c. greatest
    d. smallest

25. When there is just enough friction to prevent overshoot, the system is said to be
    a. overdamped
    b. underdamped
    c. critically damped
    d. damped insufficiently

CHAPTER 7

SYSTEMS TESTING AND TEST EQUIPMENT

Because of design characteristics, any guided missile requires a rather large amount of special support equipment, each unit of which plays a part in getting the missile into the air. Support equipment includes items such as air compressors, loading skids, launching racks, and handling tools of special types. It also includes systems test equipment used for making electronic and electrical checks on the guidance-control section of the missile.

The latter type of support device, the systems test set, provides the subject matter of the present chapter. The following pages contain illustrations and discussions of the essential types of components and circuits employed in missile checkout. Descriptions of test procedures and also of related missile equipment are included when necessary to make clear the purposes of the test-set circuitry. The term system, as used here, refers to the missile section containing those components which detect errors, determine courses, direct and perform all corrective actions, and which in general, are required in the processes of guidance and control.

Functions of Systems Test Sets

The effectiveness of an air-launched missile depends largely upon the operation of the guidance-control system, which must function perfectly if the missile is to achieve the high degree of reliability of simpler weapons such as the rocket. To insure this reliability is the primary function of the associated test set, which provides the means for subjecting the missile to a thorough confidence checkout before it is placed in ready storage or loaded on an aircraft.

Systems test equipments differ because of variations in the missiles for which they are designed; however, most perform the same basic functions and meet the same fundamental requirements. These can be summarized briefly by the following list.

1. Self check. In order to make thorough confidence checks, the test set must contain provisions for making rapid checks of its own performance prior to running an acceptance test on the missile system.

2. Flight simulation. It is necessary to check the missile system under conditions that approximate those of actual operation. Hence, the test equipment must contain signal generating circuits for developing inputs that simulate normal, in flight signals.

3. Provision of objective test results. One of the leading requirements is that test results be indicated in an objective manner and provide conclusive evidence concerning the condition of the missile section.

4. Isolation of malfunctions. In addition to making acceptance checks, the test set must be capable of indicating the location of circuit trouble as an aid in further casualty analysis and repair.

Test sets designed to meet these requirements can be grouped for convenience into two major classes: (1) automatic, or GO, NO-GO, and (2) semiautomatic, or manually operated equipments. These differ in the types of components contained and also in the amount of participation required of the operator. The automatic test set is characterized by almost complete objectivity. Selection of the tests to be performed is made by the equipment, and the results of the separate checks are indicated as either GO or NO-GO. Hence, there is no "almost good" or "almost bad" depending upon how the operator reads a chart, meter, or other indicating device.

Most semiautomatic testers require manual selection of the various test sequences performed and permit the operator to repeat a particular test as many times as necessary.

In some cases, test results are read out by means of cathode-ray indicators, in others by means of meters. As a result, the operator is required to interpret test results to a greater extent than is required with fully automatic equipment.

Automatic Test Equipment

The automatic, or GO, NO-GO, system of testing requires very little participation by the operator other than a few routine duties such as placing the missile section on the test stand and making the necessary electrical and mechanical connections. In some cases, he is also required to make several minor adjustments according to handbook instructions before beginning the missile test.

The test set is first run through a self check. If the result is satisfactory, the operator then sets the control-panel switches for the missile check, and the set automatically carries out all the operations of testing. These consist mainly of programing, monitoring, and indicating by visual means the condition of the missile as acceptable (GO) or unacceptable (NO-GO).

PROGRAMING DEVICES

The term programing refers to the processes of automatic selection, timing, and control by which the test equipment performs groups of checks in a prearranged sequence. Programing devices may be either mechanical or electronic. Two examples of the former class are described in the following paragraphs; the first is a sequence timing unit, the second a rotary stepping switch.

Sequence Timing Unit

The unit illustrated in figure 7-1 is the key device of the test set and is designed to run the missile through a sequence of checks which simulate the conditions of flight. It performs this function with the aid of associated electrical and electronic circuits, which insert input signals into the missile units in logical order and apply the resulting outputs to the monitoring equipment.

The sequence timer (fig. 7-1) controls the starting times of the separate checks, the period of time allotted to each, and the operation of the associated relays. The unit contains a series of adjustable cam rings, which are mounted on a camshaft driven through reduction gears by a fractional-horsepower motor. Groups of microswitches are located on either

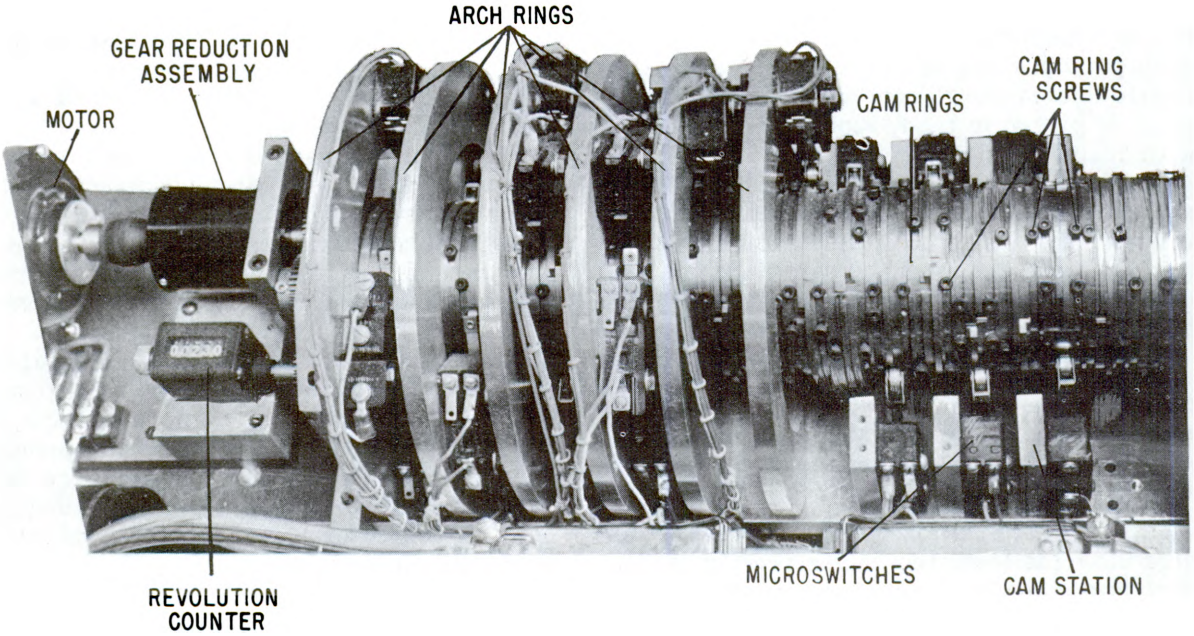


Figure 7-1.—Sequence timing unit.

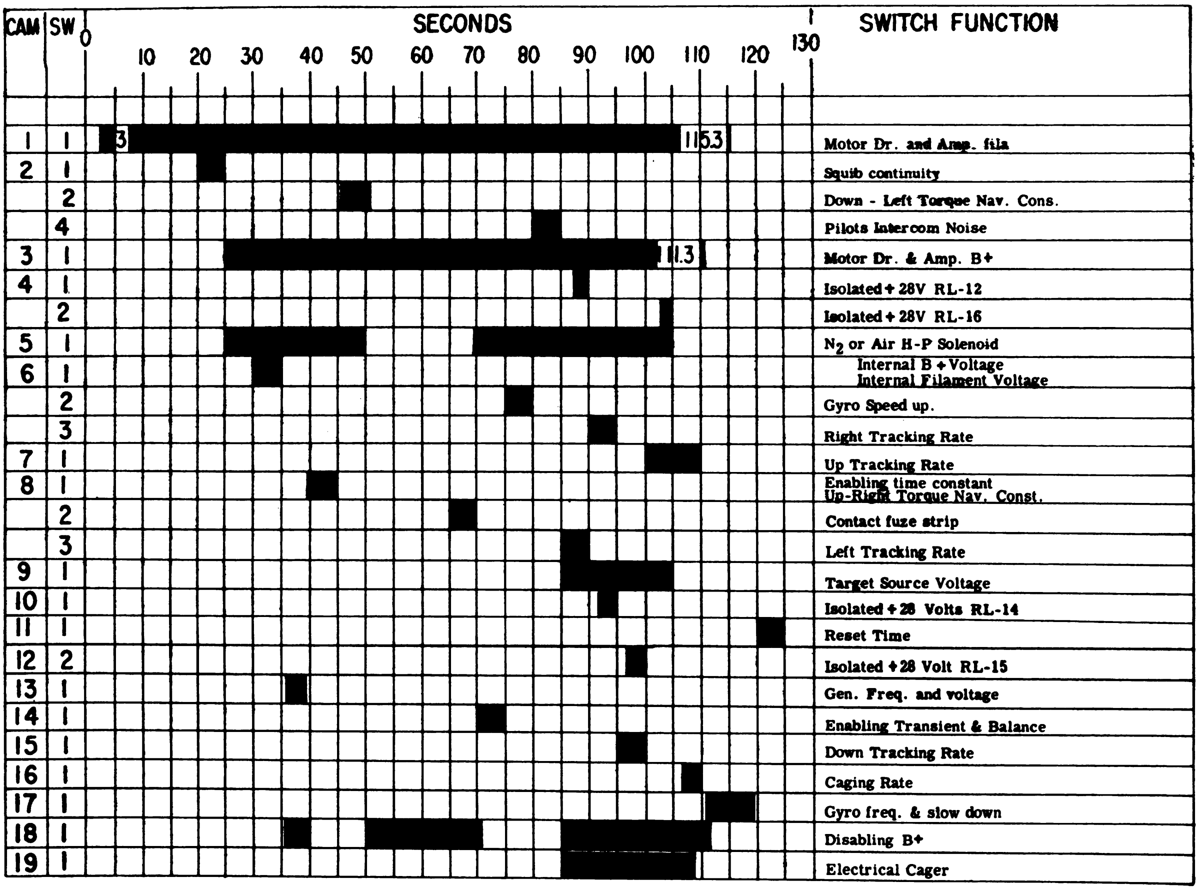


Figure 7-2.—Sequence-unit timing chart.

side of the camshaft and also on the six arch rings above it.

The microswitches are equipped with roller actuating arms. These ride on the cam rings and actuate the switches by riding down between the cam-ring segments. The driving motor is geared to rotate the camshaft through one revolution in about two minutes; and in the course of this revolution, all necessary checks are completed. With proper adjustment of the cam rings, the microswitches can be made to function at any required time and to remain actuated for the required periods.

The timing of the sequence unit is checked by means of a chart similar to the one shown in figure 7-2, which correlates cam and switch numbers with the time intervals of the various test steps. For proper operation of the equipment, the switch timing must be accurate to within 0.25 seconds; and in case of any discrepancy, the cam rings must be reset. This is done by loosening several setscrews to permit readjustment of the cam positions on the shaft.

Programing and timing devices vary widely in design from one set to another because of the variety of ways in which the test sequences are conducted. The unit just described is part of a tester which performs the entire sequence before giving a final decision. If the missile section passes all the checks, a GO indication is made after the final step; if it fails in any check, the sequence continues, terminating in a NO-GO indication plus an indication of the area containing the malfunction.

Other test equipments operate in a different way in that the programing is stopped immediately when a malfunction is first detected. Indication is then given as to its location, and the voltages applied to the missile circuits are removed to prevent possible damage to the power supplies or the unit under test. A typical example of a programing unit designed for this type of test set is the rotary switch illustrated in figures 7-3 and 7-4. The former shows the physical construction; the latter is a schematic

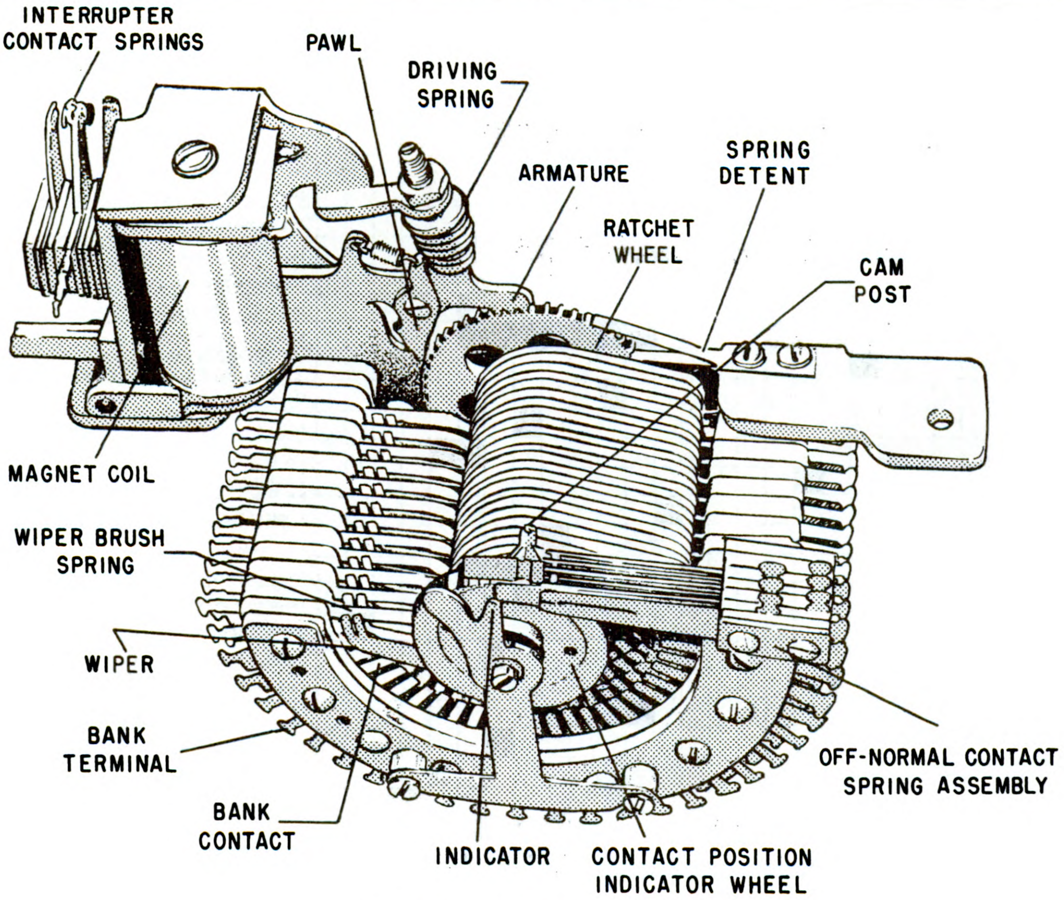


Figure 7-3.—Rotary programing switch.

which indicates the basic operation of the switch.

Rotary Switch

The rotary programing switch selects and feeds appropriate input signals to the missile units and simultaneously applies the resulting outputs to the monitoring circuits for comparison with standards. If the comparison reveals that a given output differs from the standard by an amount greater than the specified tolerance, the programer stops the equipment. If the response is within tolerance, the switch proceeds to the next check in the series and after the last test, reindexes itself for a new series.

The switch (fig. 7-3) consists of a bank assembly, a wiper assembly, and a driving mechanism mounted on a metal frame. The driving mechanism, a pawl and ratchet arrangement, is activated by an electromagnet and causes the switch wipers to move one step each time the magnet is deenergized.

The bank assembly (fig. 7-3) contains layers of electrical contacts over which the switch wipers move to select the various circuits. Each bank contains one contact called the INDEX on which the wiper rests when in the normal or HOME position. A permanent connection is maintained from the index contact to the wiper by a brush which makes sliding contact with the wiper hub.

The stepping action performed by the rotary switch results from the operation of the mechanism shown in figure 7-4. A self-cycling mode is obtained by means of two sets of contacts which are operated by the mechanical action of the armature. The interrupter contacts make and break on each cycle of operation of the electromagnet. The other set, the off-normal contacts, make at all times except when the switch is in the index position.

When the switch is off the index contact, and an energizing voltage is applied to the coil, the armature is lifted and the driving spring is compressed. The driving pawl attached to

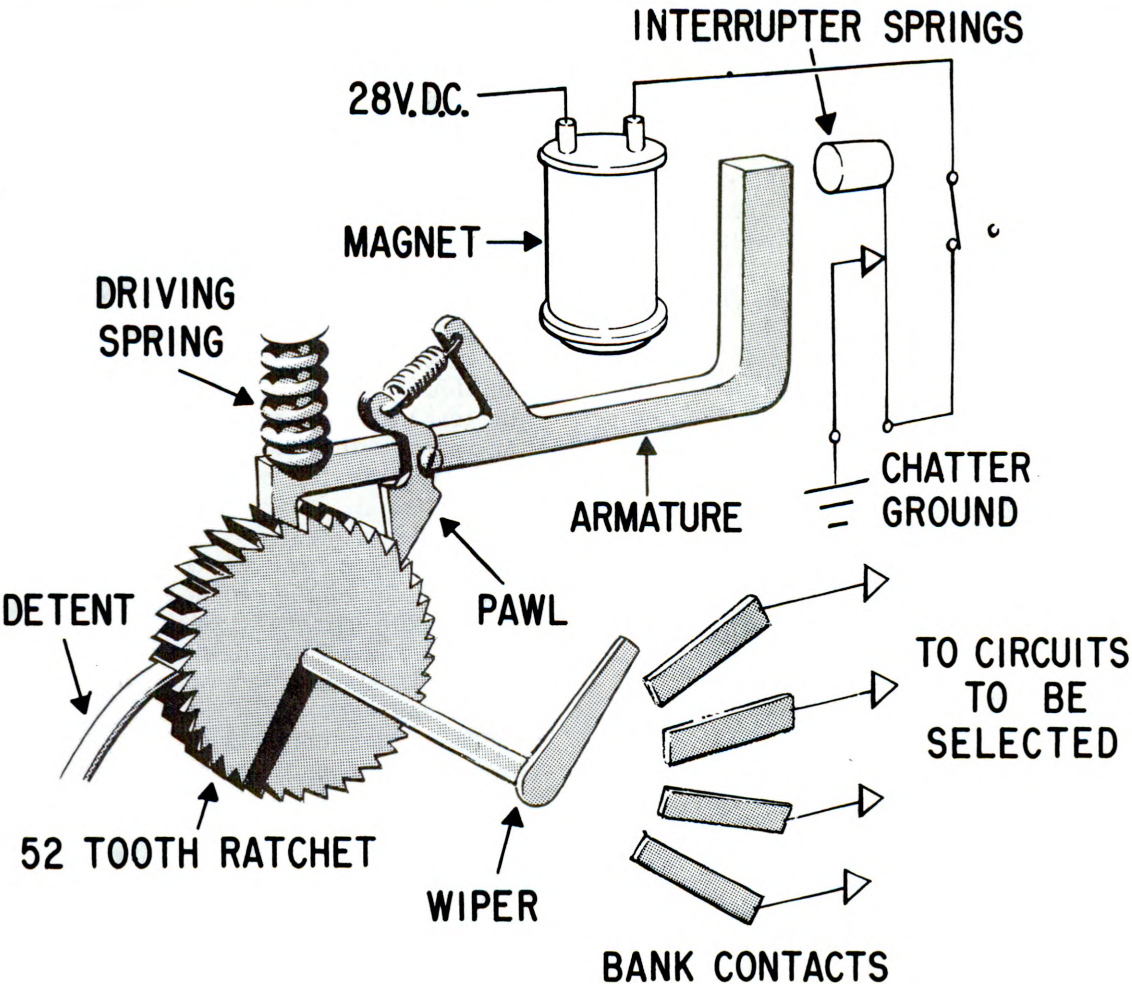


Figure 7-4.—Schematic diagram of rotary switch.

the armature is withdrawn from the ratchet-wheel tooth previously engaged and engages the next tooth. At this time, the interrupter contact is opened by an arm extending from the armature so that the ground connection is broken. This deenergizes the magnet, thereby allowing the driving spring to exert force on the ratchet wheel and move the switch to the next position. As the spring action pulls the armature away from the deenergized coil, the interrupter contacts are again closed and the stepping cycle is repeated. A spring-loaded detent engages the ratchet and prevents any backward movement of the wiper assembly when the pawl is released.

A repeat cycle timer operates in conjunction with the rotary switch (fig. 7-4). The timer is a motor-driven device which controls the action of the switch in such a way that adequate time is allowed for each separate test. It also provides the means for energizing the trouble indicating circuits. The motor drives a camshaft operating three sets of cam-controlled contacts, each of which is held closed during a certain fraction of each cam revolution. These contacts govern the operation of the circuits which energize the electromagnet and hence control the action of the stepping switch. The speed of the motor driving the camshaft is controlled during the initial steps of a check by means of a potentiometer, which is later bypassed to permit a constant motor speed.

AUTOMATIC PROGRAMER CIRCUITS

The automatic programer containing the rotary switch (fig. 7-3) may be considered as

having three basic functions. First, it selects the desired test group by placing the switching unit in the appropriate initial position. Second, it controls the order and timing of the separate test steps; and third, it stops the automatic operation when failure or malfunction is encountered in the missile and activates the trouble-indicating devices. These functions are performed by means of the circuits shown in simplified schematic form in figures 7-5, 7-6, and 7-7.

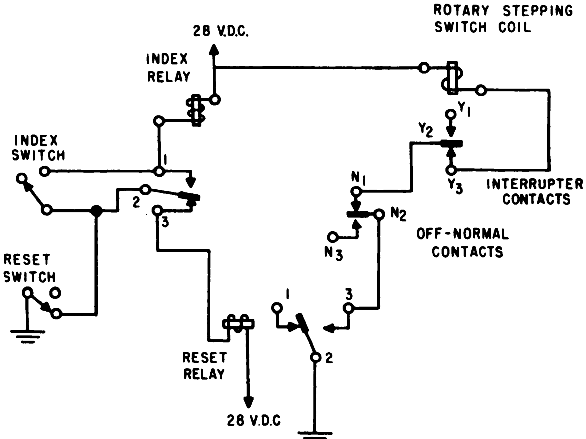


Figure 7-5.—Programer index circuit.

Index Circuit

This circuit (fig. 7-5) contains two relays and the off-normal and interrupter contacts of the stepping switch. The purpose of the arrangement is to set the rotary switch in the index position to begin the automatic operation. The action is started when the operator closes the momentary-contact index switch, thereby completing the path to ground in the 28-volt circuit that energizes the index relay. Once energized, this relay remains locked by means of contacts 1 and 2 and the reset switch.

When the index relay operates, (fig. 7-5) the reset relay (which has been normally energized) becomes deenergized, since the path to ground through contact 3 is then broken. As a result, contacts 2 and 3 of the reset relay make and complete the ground circuit of the rotary switch through the interrupter contacts and the off-normal contacts. When this circuit is completed, the switch steps around the banks in the manner previously described until it reaches the index position, where the off-normal contacts are opened. This breaks the ground circuit of the stepping switch coil and halts the stepping action.

Automatic Stepping Circuit

The stepping and timing functions of the programer are controlled by the circuit shown in figure 7-6, which contains the relays of the index circuit, two additional relays (reject and zero), and the repeat-cycle timer. The index-circuit relays are shown in the conditions present after the rotary switch has been repositioned or reindexed. The operator starts the test sequence by momentarily depressing the reset switch, thereby removing the ground connection in the coil of the index relay to deenergize it. When contacts 2 and 3 of the index relay make, the reset and reject relays both become energized. This applies 28 volts to the motor of the repeat-cycle timer, which rotates the camshaft. When the cams close contacts 6 and 7 (in the timer) the ground path is completed which energizes the coil of the zero relay.

The timer contacts (6 and 7 of fig. 7-6) break after about 25 percent of the timer cycle but the zero relay remains locked through its contacts 1 and 2. After the timer completes 70 percent of one cycle, timer contacts 3, 4, 9, and 10 close. This grounds the coil of the rotary stepping switch and picks up the armature in preparation for stepping. The step action then occurs when the timer breaks contacts 3 and 4 at about 90 percent of the cycle.

After leaving the index position, the off-normal contacts in the rotary switch assembly are closed, but self-cycle operation is prevented since the reset relay (fig. 7-6) remains energized. With each complete revolution of the camshaft in the repeat-cycle timer, the entire cycle repeats and the rotary switch moves one step.

During the first two steps, the speed of the motor in the repeat-cycle timer can be varied but in the remaining steps, the speed is fixed since the speed-control potentiometer is bypassed. Contacts 9, 10, and 11 in the timer operate in conjunction with the contacts of the trouble relay and the reject relay, the action of which is to disconnect the 28-volt lead to the timer motor when malfunctions are discovered. In this event, the reject relay becomes deenergized and the rotary switch ground lead is shifted from the normal path to a current limiting resistor. This prevents the switch from stepping so that the sequence is stopped

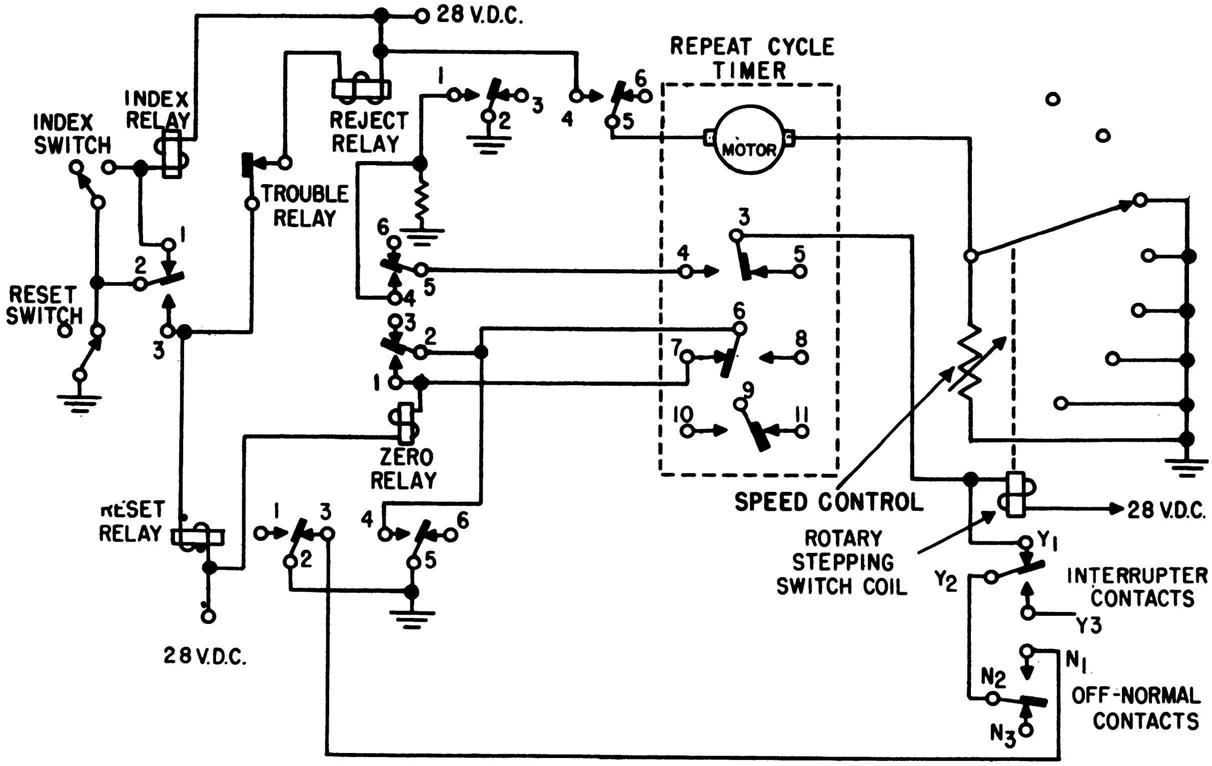


Figure 7-6.—Automatic stepping circuit.

and the trouble relay circuit then activates the malfunction indicator.

Trouble Relay Circuit

The automatic test set detects malfunctions in the missile components by comparing the output voltages with standard reference potentials. When any output differs from the corresponding reference voltage by an amount greater than the specified tolerance, the voltage monitor circuits energize the coil of a voltage sensitive relay, which activates the trouble relay circuit.

The trouble circuit, shown in figure 7-7, has the following overall operation. The trouble relay is energized when the voltage-sensitive relay picks up a contact which grounds the coil. As a result, voltage is applied to a lamp which indicates the presence of a malfunction. In the case of a power-supply check, the particular voltage under test is also indicated. The missile high-voltage relay is deenergized and removes B-plus from the missile circuits. The repeat-cycle timer is stopped and a ground is applied to a flasher circuit which causes the indicator lamp to blink on and off. At the same time, the rotary stepping switch is stopped at that point in the sequence which corresponds to the test step at which the malfunction was found.

AUTOMATIC MONITORING CIRCUITS

The processes of monitoring and programing are the two essential operations in automatic checkout equipment. The programer not only controls the circuits that feed test inputs to the missile components; it also selects the proper test points for obtaining output data and attaches these points to the monitoring devices. These usually consist of electronic circuits containing switches and relays and one or more lamps, meters, or other form of indicating device. The monitors make the checks required, either by indirect methods (as in resistance checks) or by direct comparison of output data with built-in references, and then display the results by means of the indicators. The items most frequently monitored during checkout are continuity and resistance, output signal voltages, and wing positions.

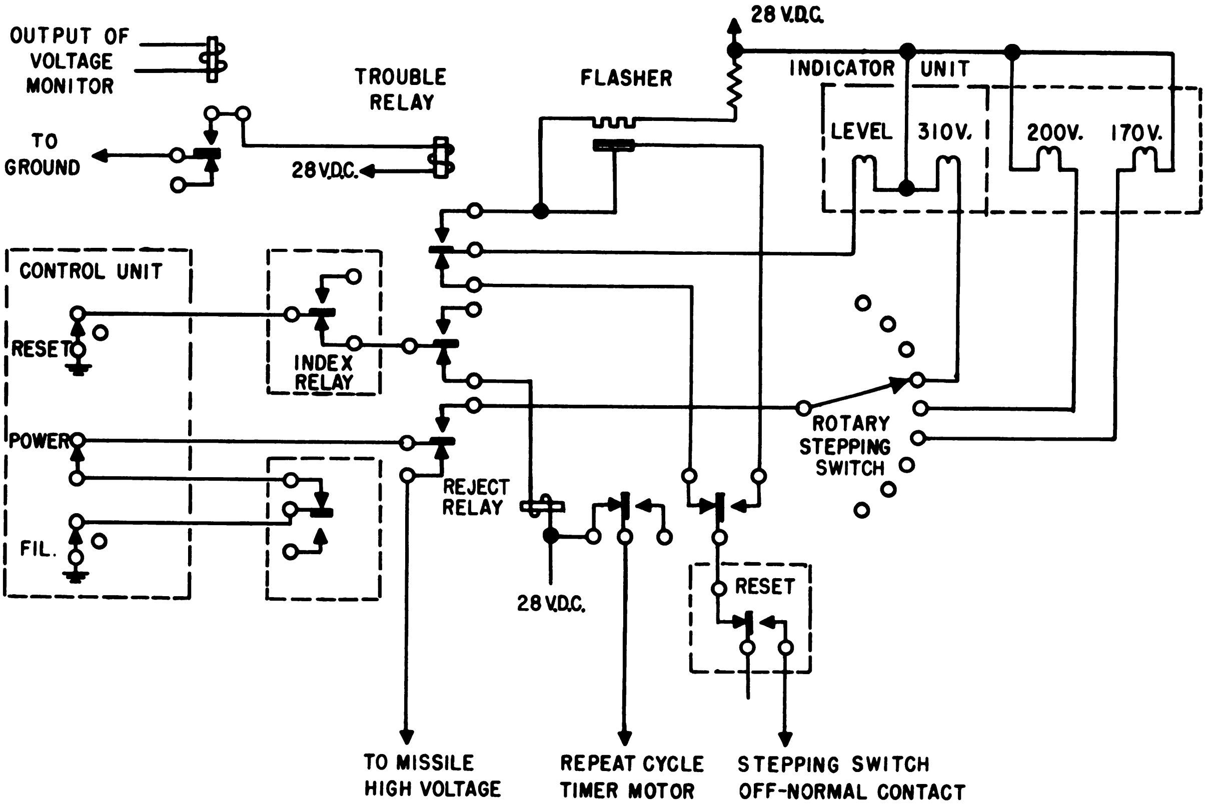


Figure 7-7.—Trouble relay circuit.

Automatic Continuity Tests

The circuits in figure 7-8 are typical examples of continuity checking equipment. In (A), the element under test, a single conductor (such as that of a missile squib circuit), is inserted in the transistor circuit between the base and ground. If the resistance is less than a certain critical value, the collector current is sufficiently strong to energize the relay, thereby causing the indicator lamp to go out, signifying a satisfactory check. If the squib circuit is open or has abnormally high resistance, the collector current is too weak to energize the relay and the lamp remains lighted to indicate a circuit fault.

In (B) of figure 7-8, the circuit is essentially the same except for the method of indicating results of the checks. Also, a stepping switch is employed to provide a multiple test series for checking continuity in units such as cable harness or in the leads connecting the contacts of relays. The circuit operation is similar to that described previously. The separate conductors in the cable are connected in the transistor circuit one at a time as the rotary switch continues to step. If any conductor is open, the transistor ceases to conduct so that the relay becomes deenergized, thereby stopping the motor in the timing unit and halting the rotary switch. In order to prevent jerky operation, the wiper contacts in the rotary switch are of the make-before-break type. The circuits in both (A) and (B) can be used, when suitably modified, to check for shorts and grounds in cables as well as for continuity.

Voltage Monitoring Circuits

During a systems test, numerous voltages produced by the missile units must be checked to insure that they are within specified tolerance limits. Two examples of the circuits used for this purpose are given in figures 7-9 and 7-10. The former, a transistorized circuit containing Zener diodes, employs potentiometers to establish the tolerance values. The latter circuit is a somewhat more complex arrangement in which a T-network serves as the reference element.

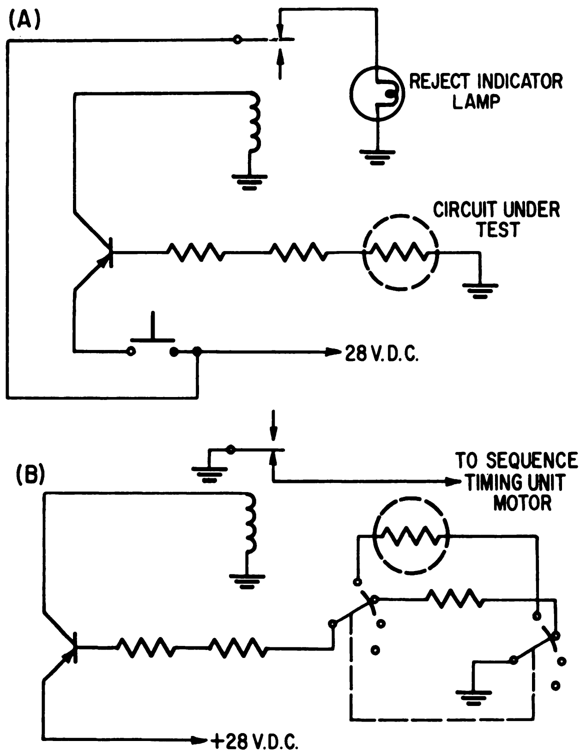


Figure 7-8.—Automatic continuity tests; (A) single conductor; (B) multiconductor cable.

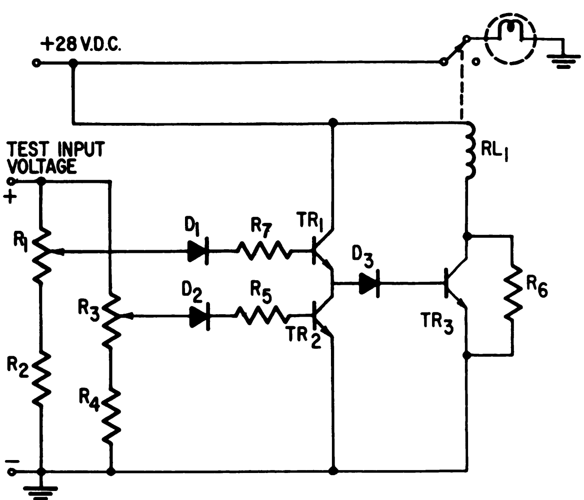


Figure 7-9.—Voltage monitor circuit containing Zener diodes.

The operation of the monitor shown in figure 7-9 depends largely upon the ability of a Zener diode to conduct in the backward direction when the applied voltage exceeds a certain critical value. Three of these diodes are included in the circuit, together with three transistors and a relay. Potentiometer R_1 is adjusted to determine the lower limit of acceptable voltage, while the setting of R_3 determines the upper, or maximum, limit.

Before application of an input voltage, the Zener diodes are in the nonconducting state and hence, the transistors are effectively open circuited. The relay coil conducts a small current, which is insufficient to energize the relay so that the indicator lamp is then illuminated.

When a test voltage of sufficient amplitude (greater than the minimum acceptable value) is applied, diode D_1 breaks down and transistor TR_1 conducts. This develops a voltage drop across diode D_3 great enough to cause breakdown, which causes TR_3 to conduct through the emitter-collector circuit. The sum of the normal current in the relay coil plus the collector current is then great enough to energize the relay. As a result, the lamp is extinguished thereby indicating a satisfactory test.

Input voltages less than the minimum acceptable level fail to break down diode D_1 (fig. 7-9) so that the sequence of events just described does not occur, and the lamp remains lighted. Also, if the voltage under test is above the upper tolerance limit, the voltage across diode D_2 is great enough to cause breakdown, thereby initiating conduction in the emitter-collector circuit of TR_2. In this case, the voltage developed across diode D_3 is too low to cause breakdown and TR_3 fails to conduct. As a result, the relay is not energized and the failure lamp continues to burn.

The action of the transistorized monitor (fig. 7-9) can be summarized in the following way. If the applied missile voltage is too low, none of the transistors conduct. If too high, TR_1 and TR_2 conduct but TR_3 remains cut off. If the voltage is within tolerance limits, TR_2 remains cut off while TR_1 and TR_3 conduct.

The circuit in figure 7-10 performs essentially the same type of checks as the transistorized monitor. It operates in conjunction with equipment similar to that shown in figures 7-5 through 7-7 and serves to operate a trouble relay and a reject mechanism. The basis of operation is comparison of the missile voltage with a reference potential by means of a T-network. Output from the network is a d-c voltage, which is applied to a 400-cycle chopper and converted to square waves. These, after amplification in a standard two-stage amplifier, are rectified in the bridge circuit. The result

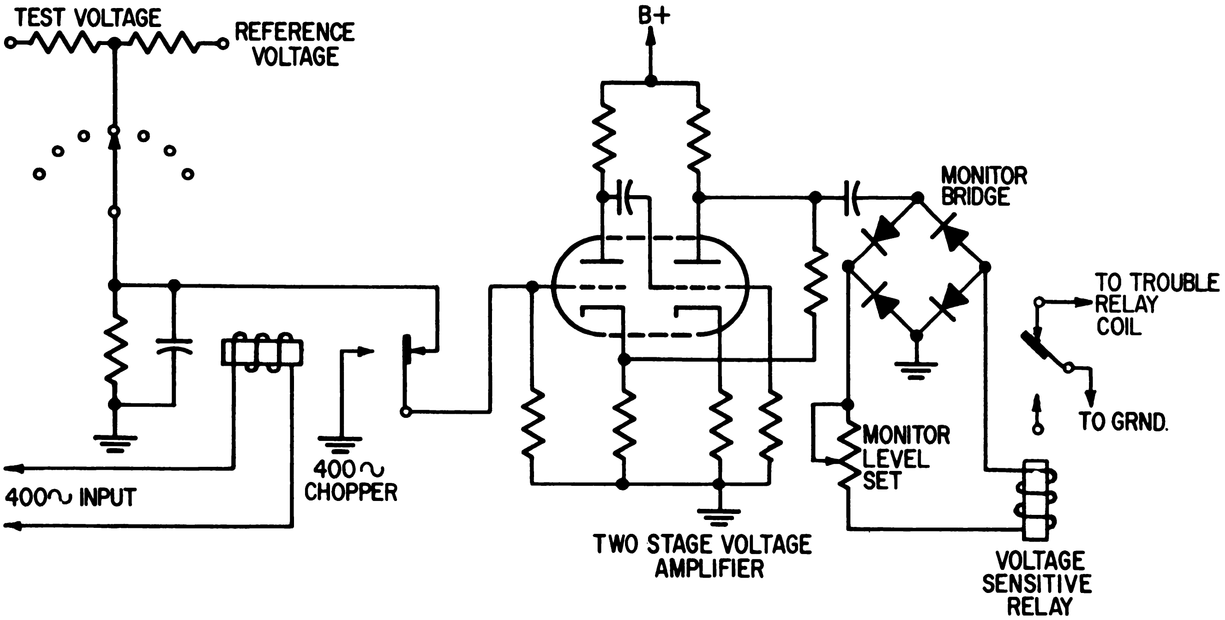


Figure 7-10.—Automatic voltage monitor containing a bridge rectifier.

is a unidirectional current which flows in the coil of the voltage-sensitive relay.

The monitor (fig. 7-10) is designed so that inputs to the chopper greater than the specified tolerance (usually in the order of 150 millivolts) cause the voltage-sensitive relay to be energized. In turn, this causes the trouble and reject relays to operate so that programing is stopped and a reject indication is given. The tolerance limit is determined by the setting of the rheostat labeled Monitor Level Set.

Wing-Monitor Circuits

The wing-monitor section in an automatic test set is illustrated in the block diagram in figure 7-11. The principal function of the monitor is to evaluate the responses of the missile wings to test inputs that simulate the inflight signals resulting from displacements in attitude and heading. This is accomplished by combining voltages picked off from the missile wing potentiometers with standard

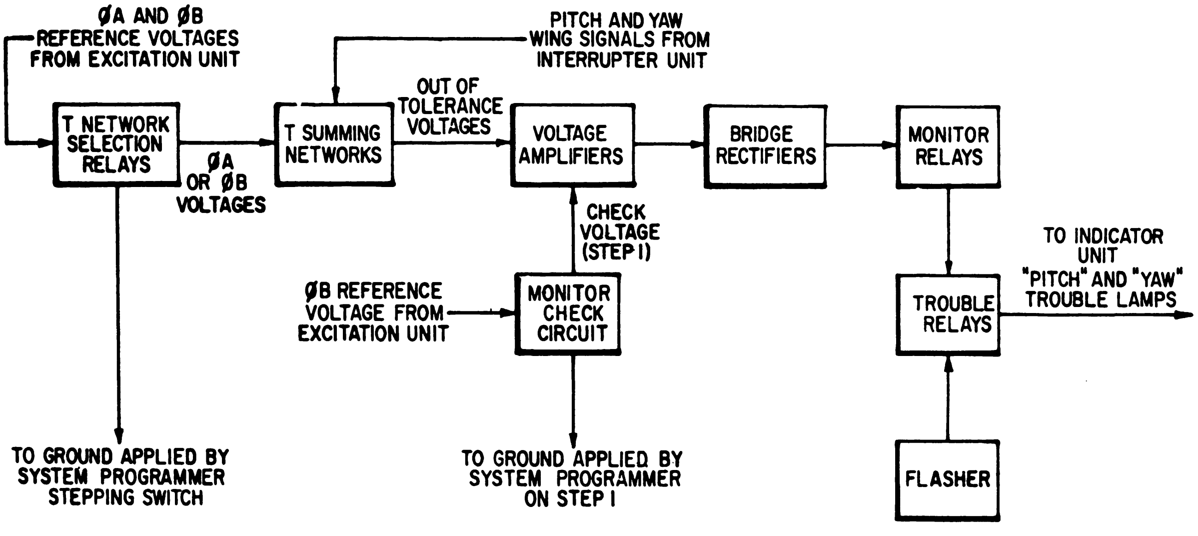


Figure 7-11.—Block diagram of automatic wing monitor.

reference potentials. The combination is made in T-networks, and the resulting voltages are applied to circuits of the type illustrated in the preceding section (fig. 7-10). The latter circuits, in turn, actuate the trouble relays and the indicating devices.

During checkout, each channel of the missile control system is tested under numerous error conditions so that many different combinations of T-network resistors and reference voltages are required. The necessary selections are made by relays in the block at the extreme left in figure 7-11. Relays are also the principal components in the monitor-check circuit, which provides the means for running self-checks of the equipment prior to missile checks. The operation of these circuits and of the remaining parts of the monitor can be studied best by use of a schematic diagram of the type shown in figure 7-12.

The signals to be monitored originate in a potentiometer (fig. 7-12), the wiper of which is positioned by the missile pitch wings. The opposite ends of the potentiometer are fed out-of-phase, sine-wave voltages, so that the electrical center is effectively at ground potential. With the wiper in any position other than center, it picks off a voltage proportional in amplitude to the wing displacement and with a phase determined by the direction of displacement.

The initial step is the self check, which is made with the potentiometer set at electrical zero, corresponding to the neutral position of the wings. It is begun by energizing the monitor-check relay, which applies a 0.4-volt test input to the pitch monitor circuits. If circuit operation is normal, the test voltage is sufficiently large to energize the monitor relay. This action prevents the trouble relay from becoming energized by removing the ground connection from the coil. However, if the monitor relay fails to energize when the test input is applied, the trouble relay is then energized and an indication of malfunction in the test equipment is made.

In the second step of the wing-monitoring procedure, the missile circuits are compensated for lack of balance by bringing the drift-balance relay (fig. 7-12) into operation. This

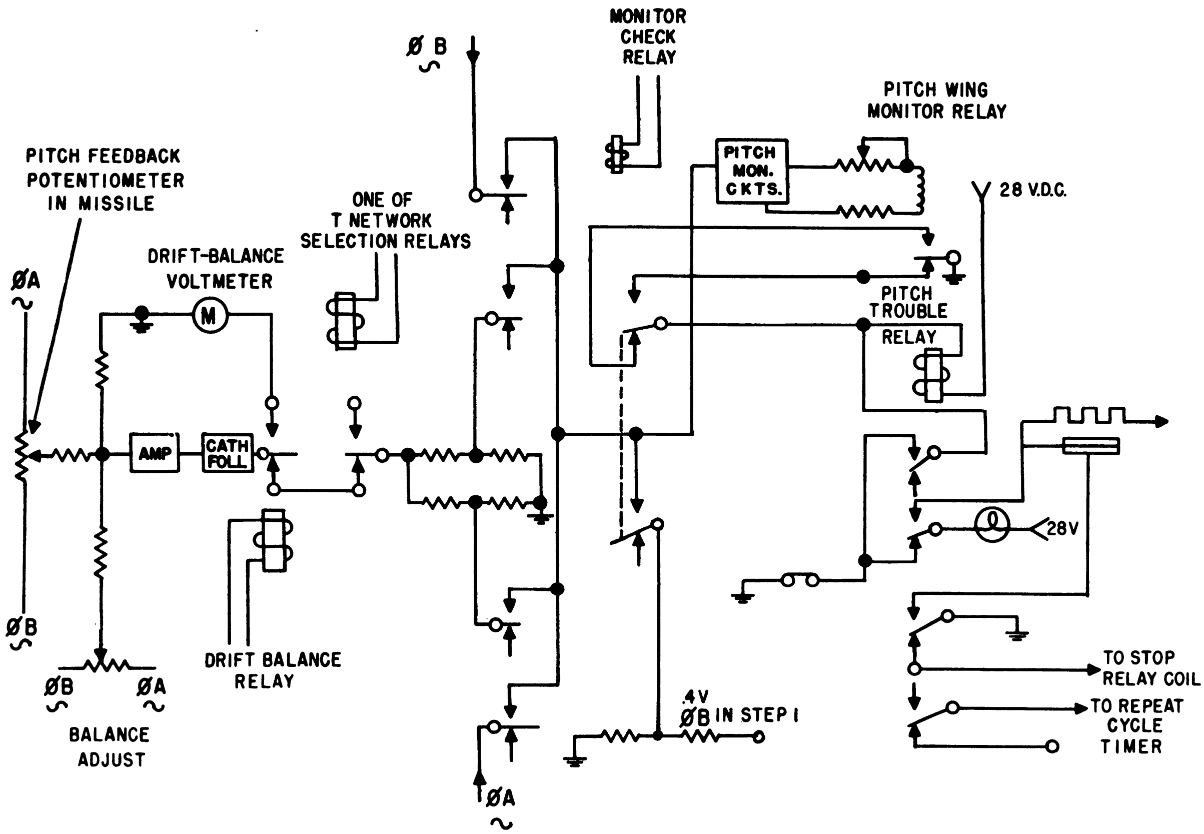


Figure 7-12.—Wing-monitor control circuits.

is done by applying the outputs of the wing potentiometers to the summing networks with the missile in a simulated boresight condition. The resultant voltage should then be zero; and if some other voltage appears at the input of the monitor, this indicates the result of drift or unbalance in the control circuits. If the amount of unbalance is within tolerance, addition of a drift-balance voltage is made to cancel out the undesired voltage. The results of this addition are indicated by the drift-balance voltmeter, which reads zero when exact cancellation is reached. However, if the wing drift is out of tolerance, it cannot be compensated by the adjustment; and if so, repairs must be made before the test can proceed.

In the following steps in the series, various input error signals are applied to the missile units, resulting in displacements of the wings and of the pickoff potentiometers. With the drift-balance and the monitor-check relays (fig. 7-12) both deenergized, the wing signal is fed to a specific T-network designed to sum the reference and error voltages to approximately zero if the missile response is acceptable. If the output voltage of the T-network is out of tolerance, current flow in the coil of the pitch monitor relay is sufficiently strong to energize it, thereby grounding the coil of the pitch trouble relay and deenergizing the programing circuits. Actuation of the pitch trouble relay also brings a flasher into operation together with a trouble-indicator lamp.

Manual Test Methods and Test Equipment

In contrast with completely automatic test equipment, manually operated test sets require considerable participation by the operator. Manual testing involves the use of semiautomatic equipment and may be defined broadly as the system of checkout wherein the operator has control and choice of the following items:

1. The particular test to be performed.
2. The length of time a given check is run and the number of times it is repeated.
3. The sequence in which the separate test steps are performed.

In addition to making these choices, the operator must analyze the results of the tests on the basis of his observations of output data and the comparison of these with standard outputs.

In physical appearance, most semiautomatic test sets closely resemble automatic equipments; however, the components and circuits of the two basic types often differ widely. The remainder of this chapter deals with typical examples of circuits contained in semiautomatic equipment and the types of tests performed by them. The circuits described are selected to illustrate fundamental principles rather than to teach the operation of particular sets. For information on detailed procedures and specific sets, the trainee must consult the appropriate missile and test-equipment handbooks.

In order to understand the purpose and functioning of the circuits discussed in the following pages, it is necessary to begin with a brief description of the basic operation of the missile system to which they relate. Following this are discussions of the major tests, metering and monitoring circuits, signal-generator equipment, and representative output-indicator displays.

BASIC MISSILE OPERATION

The block diagram in figure 7-13 gives an example of a complete guidance-control section of the type tested by semiautomatic, manually operated equipment. The missile containing this section is a semiactive homing weapon which employs Doppler radar (the basic features of which are discussed in chapter 6, *GF 3 & 2,* NavPers 10379).

The operation of the missile units involves several signals of different frequency which must be considered in the discussion of test equipment. These signals are referred to in the following sections by means of letter designations because of security restrictions. The designations used are those given in table 7-1.

The section shown in figure 7-13 can be considered as containing two major testable entities: the target-seeker and the control system. The former is made up of a receiver, a speedgate, and head-control equipment. The latter contains the missile autopilot and the hydraulic and mechanical components which produce wing motions.

The Target-Seeker Receiver

During missile flight, the launching aircraft illuminates the target with frequency-modulated, microwave energy. Some of the

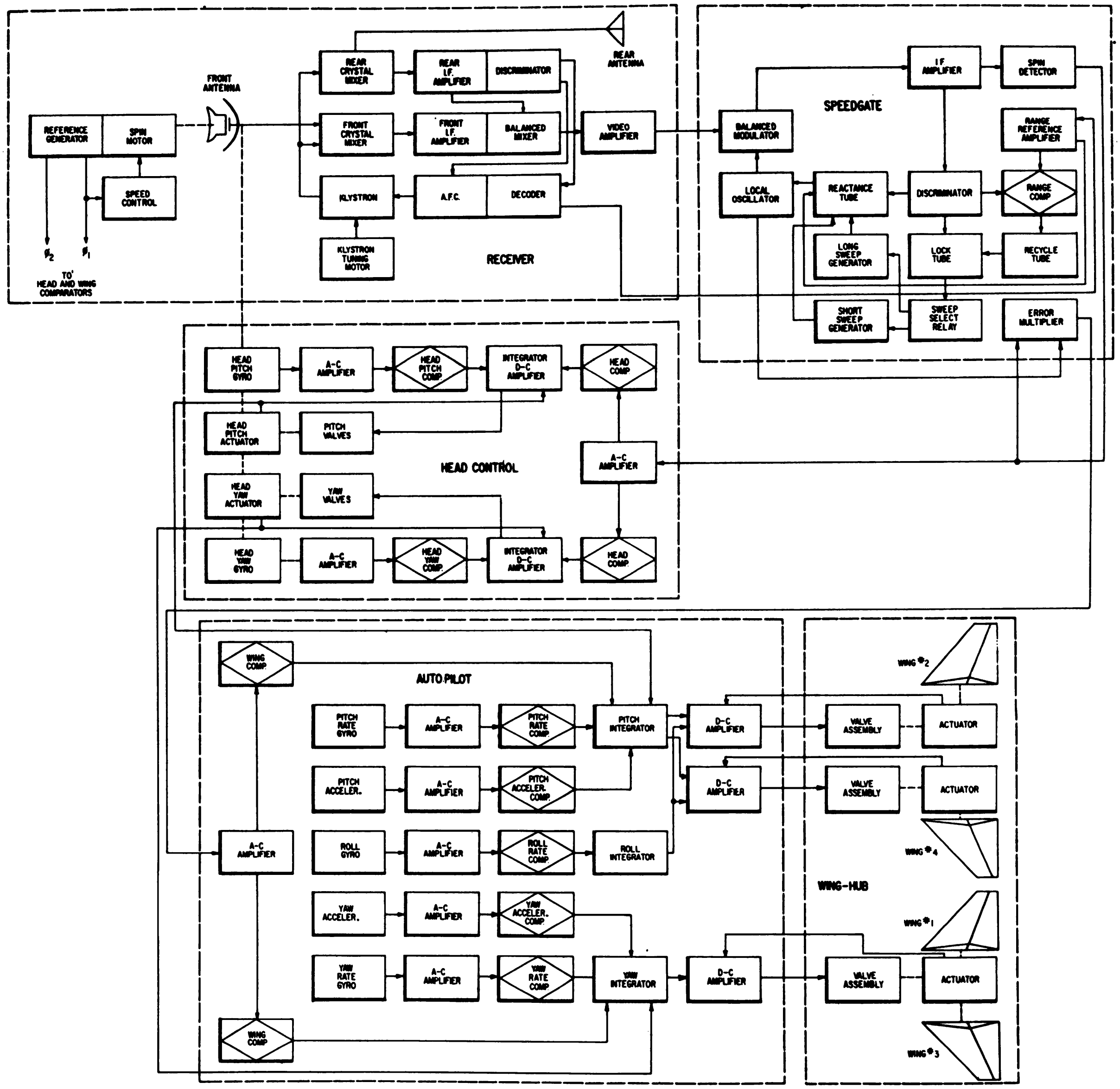


Figure 7-13.—Block diagram of guidance-control section of semiactive missile.

energy reflected from the target is picked up by the front antenna of the missile which consists of a small parabolic reflector and a spinning trislot element. The parabolic reflector focuses the energy on the trislot element which is rotated by a spin motor at a frequency of D/3; however, the electrical scanning rate of the trislot element is three times the mechanical rotation rate, or D. This action provides target-angle information with reference to the antenna boresight line in the form of D amplitude modulation of the received signal. The directional information is detected after speedgating, as explained in a subsequent paragraph.

A reference signal generator is mechanically coupled to the spin motor and supplies the D frequency to the head and wing comparators (fig. 7-13), which are a group of diodes that compare the reference signal with the phase and amplitude of the error signal and provide appropriate d-c outputs to pitch and yaw amplifiers. The error signal is received from the spin detector in the speedgate.

The reference generator also provides a feedback loop through the speed control circuit to the spin motor. The speed control circuit acts as a discriminator circuit and provides controlling signals to the spin motor to maintain the mechanical rotational rate constant at D/3.

A polarization filter (grating) covers the face of the parabolic dish to eliminate undesirable cross-polarization components resulting from the polarization-sensitive trislot system.

The received radar signal is shifted in frequency due to the Doppler effect realized from moving targets. The signal is then coupled to the front balanced crystal mixer where it is mixed with a signal from the klystron local oscillator. The klystron is automatically tuned to E above the illuminator signal prior to missile launching by the klystron tuning assembly located in the pylon of the launching aircraft. The klystron tuning assembly controls the klystron tuning motor in the missile.

The antenna at the rear of the missile picks up the r-f signal directly from the illuminator. This signal is coupled into the rear balanced crystal mixer where it is also mixed with the klystron local oscillator signal. The resultant signal is amplified by the rear i-f amplifier whose center frequency is E. If the signal frequency varies from E, the discriminator will provide a controlling voltage to the AFC circuit. The latter circuit in turn provides a vernier control of the klystron frequency by controlling its repeller plate in such a manner that the klystron local oscillator is kept E above the transmitted signal from the illuminator.

The klystron AFC receives a coding signal which identifies the illuminator. If the coding is not present, the AFC will not remain locked on the rear signal but will go into a search mode. The C frequency is recovered in the decoder and is provided to the range comparator in the speedgate as a reference signal.

Mixing the front signal with the klystron local oscillator signal at the front balanced mixer yields an E signal with Doppler. This signal is amplified by the front i-f amplifier and fed to another balanced mixer which heterodynes the front and rear i-f amplifier outputs to produce a Doppler output. The Doppler signal from the balanced mixer is amplified by the video amplifier and coupled to the balanced modulator in the speedgate.

Speedgate

The primary purpose of the speedgate is to provide a narrow band gate to track a Doppler signal frequency so that target directional error information may be detected. This error information is used to direct the missile to the target. The balanced modulator heterodynes the Doppler signal from the video amplifier and the signal from the local oscillator to produce a new i-f of G plus 95 (table 7-1).

Table 7-1.—Frequency designations.

Frequency	Function
A	Carrier frequency of the illuminator.
B	Frequency of the coding signal.
C	Frequency of the ranging signal.
D	Frequency of the antenna lobing on the missile.
E	IF of missile receiver.
F; G	Frequencies in the Doppler spectrum.

The local oscillator is swept through a band of frequencies so that, when an incoming Doppler frequency is detected in the balanced modulator, the mixing of the two signals will yield the correct i-f. This is accomplished by a sweep generator which controls a reactance tube and, in turn, directly controls the operating frequency of the local oscillator. When a Doppler signal is present, producing an i-f of G plus 95 at the output from the balanced modulator, the G plus 95 is amplified by the i-f amplifier and coupled to a discriminator. Since the Doppler frequency changes, and the speedgate has a narrow bandwidth, automatic frequency control of the local oscillator must be provided. The discriminator will detect any small changes in frequency and provide a corresponding change in control of the reactance tube which will shift the local oscillator frequency to maintain a constant i-f of G plus 95.

While a Doppler signal is present within the narrow gate, the D amplitude modulation from the signal is detected by the spin detector. The D amplitude modulation is a result of conically scanning the trislot element,

as was explained previously. The D signal from the spin detector is an error signal with its amplitude proportional to the amount of angular displacement of the target from the line of the antenna boresight, and with its phase a function of the direction of the target off the boresight line.

It is evident that in order to obtain target directional error information, the speedgate must continuously track the Doppler signal. It is also evident that the speedgate must search the correct band of frequencies to pick up the anticipated Doppler signals.

When a coherent Doppler signal is present in the speedgate, the search condition of the speedgate (sweeping the local oscillator) is stopped by a lock circuit.

The discriminator provides the output to the lock tube when a Doppler signal is present to initiate the lock condition. The lock tube cuts off the sweep generator, which results in the reactance tube controlling the local oscillator only through the AFC loop.

Noise is also present and is capable of locking the speedgate; therefore, a method of determining whether the speedgate is locked on noise or a coherent Doppler signal must be provided. Also, if the speedgate is locked on noise, a means of recycling the speedgate must be provided.

The method of determining whether the signal in the speedgate is a coherent Doppler signal or noise is accomplished by frequency modulating the transmitted signal at C frequency. The frequency-modulated signal is allowed to pass through the receiver and into the speedgate. If it is a Doppler signal and is mixed with the local oscillator signal in the balanced modulator, the output will also have C-frequency modulation. However, if the output from the balanced modulator does not contain the C-frequency modulation, then the signal is noise.

Take the condition that a coherent Doppler is present, that is, the C-frequency modulation is present. The C frequency is detected at the output of the discriminator and is coupled to the range comparator. Here the C frequency from the discriminator is compared with a reference C signal coupled directly from the range reference amplifier. The output from the range comparator will be a negative d-c signal which will prevent the recycle tube from firing. This allows the lock tube to continue operating and speedgate lock is maintained.

On the other hand, when the speedgate has locked on noise, the output from the balanced modulator does not carry the C-frequency modulation. Therefore, this frequency is not present at the range comparator. Under these conditions the range comparator provides a positive d-c signal to the recycle tube causing it to fire. When the recycle tube fires, it causes the lock tube to be cut off. With the lock tube cut off, the sweep generator is allowed to operate and the speedgate goes into the search condition.

The primary output from the speedgate is the D-frequency radar error signal from the spin detector. This signal is applied to the a-c amplifier in the head-control section and to the error multiplier circuit in the speedgate.

Head Control

The head assembly is gimbal mounted, and is positioned by hydraulic actuators in pitch and yaw. Stabilization and control of the head is generally achieved as follows:

A radar error voltage from the spin detector in the speedgate is applied to the a-c amplifier feeding the head comparators. Each head comparator applies an error voltage proportional to the appropriate integrating d-c amplifier in pitch and yaw. Another input to each integrating d-c amplifier comes from the head pitch or yaw gyro. Output voltages from the integrating d-c amplifier then operate the proper valves controlling the head hydraulic actuators which properly aim the head so as to track the target. Both the head pitch actuator and head yaw actuator are equipped with followup potentiometers. The output from each followup potentiometer is applied to the corresponding wing channel integrator in the autopilot and, prior to launch, to the integrating d-c amplifier in the head control.

Autopilot

The autopilot operates with a closed-loop servo system. Resistive mixing networks are provided at the input to the servo for error and feedback mixing. Amplification is obtained electrically in the d-c amplifier and hydraulically in the valve. Hydraulic actuators provide the motive power, and followup (feedback) is obtained by means of a voltage derived from the potentiometer connected directly to the wing. The error-signal output from the spin detector in the speedgate after passage through the error multiplier is applied to the a-c amplifier feeding the wing comparators.

The wing comparators compare the phase of the error multiplier output with the reference generator (in the r-f head) two-phase output. Phase 1 of the reference generator is applied to the yaw comparator, while phase 2 is applied to the pitch comparator.

The wing comparator output is applied to the pitch integrator where it is combined with the output voltages from the pitch rate gyro chain, the pitch accelerometer chain and the head pitch followup potentiometer.

The pitch integrator output is applied to the wings No. 2 and No. 4 d-c amplifiers. The d-c amplifiers operate the valve assemblies controlling the wings for pitch control. A voltage sample from the wing hydraulic actuator potentiometer is applied to the appropriate d-c amplifier to form a closed-loop servo system.

The d-c amplifiers for wings No. 2 and No. 4 also receive an input from the roll gyro for roll rate stabilization. When a roll rate is encountered, an output from the roll gyro is applied differentially to wings No. 2 and No. 4 amplifiers, and cause the wings to be deflected to correct for roll.

The yaw channel operates in a manner similar to the pitch channel; the difference being the absence of roll gyro input to the yaw channel and the absence of differential movement of wings No. 1 and No. 3.

MAJOR TEST GROUPS

Despite the apparent complexity of the missile, the tests needed to ascertain its condition are comparatively few in number. To determine if a particular missile is acceptable, a confidence check is performed during which each section of the weapon capable of affecting the flight path is tested in the operating condition. The principal functions evaluated are those of the autopilot in response to errors in pitch, yaw, roll, and skid and also of the guidance components in response to signals simulating changes in speed, range, sensitivity, and target bearing. The tests performed are classified into major groups according to function and described briefly in the following pages.

Group 1. R-F and Fuzing Tests

This group includes checks of the autotune system, rear- and front-lock sensitivity, speedgate sweep, and electronic fuzing. The missile under test requires front- and rear-microwave signals which differ by a few kilocycles, the difference representing the Doppler shift. The signal radiated into the missile radome, the front signal, is modulated with ranging information. The rear signal, which is directed into the aft antenna, is modulated with ranging and coding information. Calibrated attenuators in both front and rear signal paths provide front- and rear-lock sensitivity test facilities.

The autotune circuitry that simulates similar circuits in the launching aircraft allows the missile to be tuned to the proper radar carrier frequency. Missile functions such as AFC (automatic frequency control of the klystron) and recycle voltage (indicating lock on a coherent Doppler) are monitored on sectored meters. Various simulated Doppler signals are generated in the test equipment and used to test the bandwidth of the speedgate.

A test which simulates the approach of the missile to the target is performed by reducing the value of the ranging frequency deviation (the amount of frequency shift of the carrier wave). The final check in the group simulates a near miss by the missile and is performed by shifting the Doppler frequency by a certain amount, thereby triggering the fuzing circuit.

Group 2. Head Drift and Head Dynamics

Checks in this group test the ability of the seeker head to remain in boresight position under zero error conditions as well as its capabilities for target tracking. If the head drift is zero, the wings are at streamline and are so indicated on a cathode-ray indicator by a spot located at the center of the tube face. If the spot is not centered, adjustments are then made on the missile units to reduce head drift to values within tolerance limits.

Head-control dynamics (the actions of the seeker head under target-seeking conditions) are checked by injecting a modulated Doppler signal into the missile. This signal simulates a target rotating about missile boresight at a fairly low frequency. As the head tracks the simulated target, the outputs of the seeker-head rate gyros are processed and applied to the wing-position indicator. If the response is satisfactory, the indicator tube displays a circular pattern with a diameter of specified value.

Group 3. Error Sensitivity and Altitude Compensation

This group contains checks of the error sensitivity of the system and of its ability to compensate for different altitudes. Error sensitivity, or error gain, is checked by reading the wing deflection, as represented by the diameter of a circle appearing on the cathode-ray indicator tube. For a fixed modulation percentage, the circle size must be of the value specified in the authorized procedure. Compensation for changes in altitude is accomplished in the missile by means of relay circuits. During checkout, these are energized to simulate altitude changes and the resulting changes in error gain are indicated by the cathode-ray tube.

Group 4. Autopilot Tests

The autopilot section of the missile is confidence checked by separate tests of roll gyro gain, rate gyro gain and phasing, accelerometer output, and integrator drift. Overall error gain of the autopilot is checked by the methods employed in group 3 checks. The motion sensing instruments are tested by mechanically moving the missile test stand to simulate motions in pitch, yaw, roll, and thrust. The equipment also provides the means for making a "yozzle" test in which the missile is subjected to damped oscillations under spring restraint. As a result of the various motions applied, the control instruments generate command voltages; these, in turn, cause wing motions, which are read out on the wing-position indicator.

TEST EQUIPMENT CIRCUITRY

MONITORING EQUIPMENT

In the performance of the major test groups listed in the preceding pages, the missile-control portion of the test set provides various commands to the guidance-control units in addition to setting the proper conditions for the tests required. The monitor section of the tester indicates various responses of the system both to commands injected into the control components directly and to microwave signals produced by the signal-generating units. In the groups of tests performed, some functions are more easily monitored by meters than by other methods. Among these are the recycle function of the missile, the action of the AFC circuitry, and the operation of the autotune system.

Recycle Monitor

The recycle operation is initiated by a conditional voltage which is developed if the missile loses either rear or front signal or if the speedgate attempts to lock on noise instead of a coherent Doppler signal. In these cases, a comparator circuit in the missile provides an output voltage which is applied to the recycle tube. The action initiated by the latter causes the speedgate to change its mode of operation from lock to search. The signal serving as a recycle voltage is applied to the lock tube, cutting it off and allowing the sweep generator to operate and revert the speedgate to the search mode.

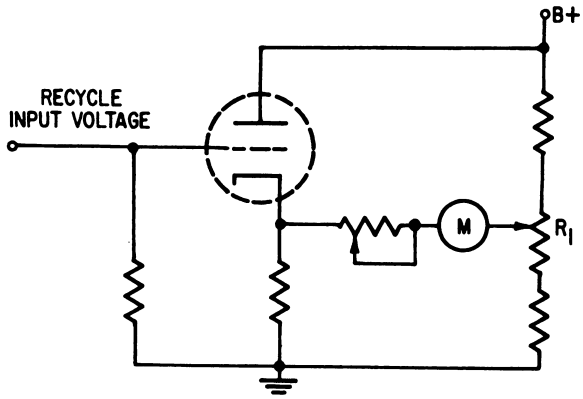


Figure 7-14.—Recycle voltage monitor circuit.

The recycle monitor circuit, shown in figure 7-14, contains a triode connected as a cathode follower. The principal function is to indicate difference current. With no signal present on the grid of the tube, R_1 is adjusted to the same potential as the cathode. With no voltage drop across the meter, no current flows and the indication is zero. When a recycle voltage is applied to the grid, the change in tube conduction modifies the cathode voltage and thereby causes the meter to indicate a value proportional to the input to the tube.

Automatic Frequency Control

The AFC voltage is dependent upon klystron operation and thus may be used as an indication

of whether the local oscillator is locked on a signal or is sweeping. When the rear r-f section is locked on the signal of the parent aircraft radar, the klystron repeller voltage is practically constant and the AFC voltage is effectively zero. However, if rear signal is lost for a period of time exceeding "slow-unlock," the klystron reverts to the search function. These changes are reflected in the output of the missile discriminator which controls the AFC voltage; hence by monitoring the latter voltage, the klystron operation can be monitored. The circuit used for this purpose is similar to that employed for the recycle check (fig. 7-14), with the exception that the meter is used in other checks and may be switched into or out of the AFC monitor circuit.

Klystron Tuning

The essential elements involved in the missile autotune checks are shown in figure 7-15. The test-set circuits are similar to those contained in the pylon of the parent aircraft and during checkout, perform functions identical with those performed by the operational gear just prior to missile launch. While on the aircraft pylon, the missile is fed a "pseudo signal" to provide klystron lock-on information. At this time, the circuit is searching; the klystron tuning motor continuously cycles and sweeps the klystron frequency over a certain range. When the klystron produces the proper frequency to develop the correct i-f signal, the control circuits cause the oscillator to lock on. In this condition, the tuning motor is stopped and fine-tuning control of the klystron is accomplished by the AFC action. During tests, the search and lock-on functions are controlled and checked by the test-equipment circuits shown in the drawing.

The tubes V_1 and V_2 (in (B) of fig 7-15) constitute a two-stage, direct-coupled amplifier with one input grounded. The output is taken between the plates (pin 6 of V_1 and pin 1 of V_2). The action is such that with the plates at the same potential, no current flows through the coils of relays K_1 and K_2; but when a difference in potential exists, current flows in one or the other, depending upon the polarity of the voltage difference, this polarity being detected by the crystal rectifiers, CR_1 and CR_2.

During the search operation, relay K_3 (fig. 7-15) is held energized by the recycle amplifier and control circuits. This causes a negative voltage to be applied to the grid of V_1 from the limit switch voltage-divider circuit. Thus, an unbalance exists between the plates of the amplifier tubes such that current flows

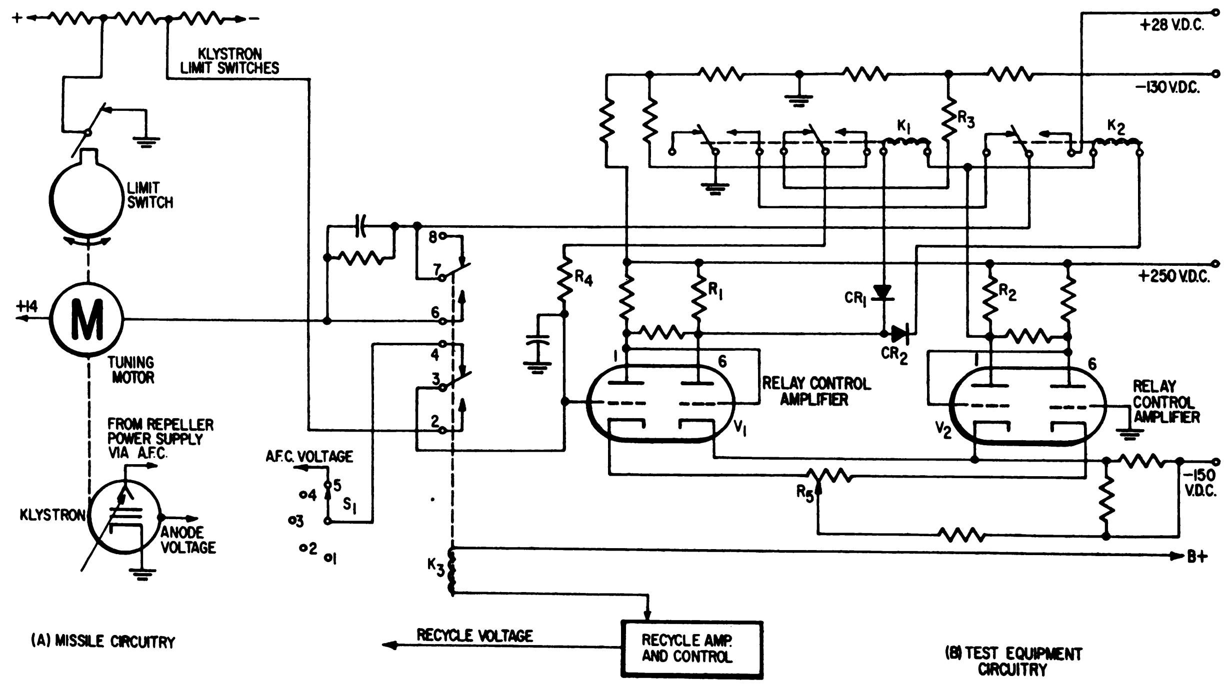


Figure 7-15.—Klystron autotune circuitry: (A) missile; (B) test equipment.

through K_2 via CR_2. This current is great enough to energize K_2 so that a positive 28-volt d-c potential is applied to the tuning motor, causing it to start cycling. When the limit switch opens, a positive voltage appears at the divider circuit and is applied to the input grid of V_1. This causes K_1 to energize and K_2 to release with the result that the tuning motor reverses in direction of rotation.

When lock on occurs, relay K_3 (fig. 7-15) is deenergized. This applies missile AFC to the motor controlling circuit and also switches an R-C network into the motor power line, slowing down motor rotation. This prevents overshoot by the motor so that it stops when the AFC is zero. The AFC system then maintains control of the klystron tuning as long as K_3 remains deenergized.

Wing-Position Indicator

The wing-position indicator is a readout device used in testing the major parameters of the missile, and is employed chiefly in measurements of dynamic response to simulated target maneuvers. These tests are so designed that any malfunction present can be isolated to a particular component, or replaceable package. The indication of malfunction is given in the equipment under consideration when the pattern on a cathode-ray tube fails to fall within the appropriate in-tolerance bands of the mask placed over the tube face.

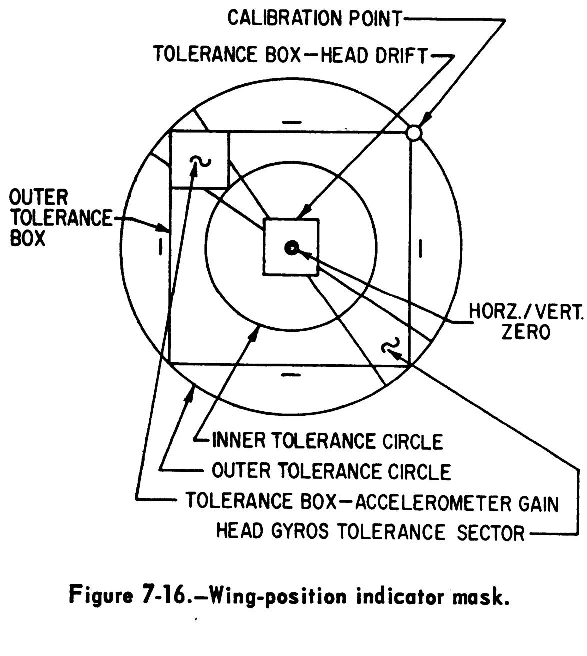


Figure 7-16.—Wing-position indicator mask.

The WPI mask shown in figure 7-16 contains a number of squares, circles, and sectors. The two circles indicate the range of in-tolerance wing deflections for specified target deviations and are used in measurements of error sensitivity. In wing-deflection measurments, for example, the guidance-signal simulator in the test set introduces a test input which simulates a target rotating at constant frequency about the missile longitudinal axis. The pitch and yaw wings then move sinusoidally, producing two voltages displaced in phase by 90 degrees in the two wing-feedback potentiometers. If the missile response is acceptable, the amplitude of the deflections must fall within certain tolerance limits. The quadrature voltages from the wing potentiometers are proportional in amplitude to the corresponding wing deflections; and when these voltages are applied to the indicator equipment, they cause a closed figure to appear on the CRT screen. In-tolerance response is indicated when this figure lies between the circles on the WPI mask.

In addition to the visual-display equipment, the position-indicator unit contains horizontal and vertical deflection amplifiers, a power supply, and various switching circuits. The principal features of the amplifiers and associated switches are shown schematically in figure 7-17.

Horizontal amplification is provided by a two-stage, cathode-coupled circuit (fig. 7-17), the push-pull output of which is applied to the horizontal deflection plates of the cathode-ray tube. The input to the grid of the first stage is selected by a ganged function switch. With the latter in position 1, both horizontal amplifier grids are grounded, and the beam of the CRT can be centered by adjustment of the Horiz. Zero and Vert. Zero controls. Position 2 of the switch permits gain adjustment of the vertical amplifier circuits. In position 3, a d-c voltage is taken from the power supply for use in calibrating the horizontal amplifier gain by means of the Yaw Cal control. With the switch at Operate, or position 4, the horizontal amplifier receives yaw signals from the missile.

The vertical amplifier (fig. 7-17) is similar to the horizontal in circuitry and operation except that two inputs are applied. With the function switch in position 2, or Roll Cal, the two grids are attached to the calibration voltage and the Pitch Cal control is adjusted to achieve gain equalization of the tubes. In the Operate position, the vertical amplifier receives pitch or roll signals from the missile.

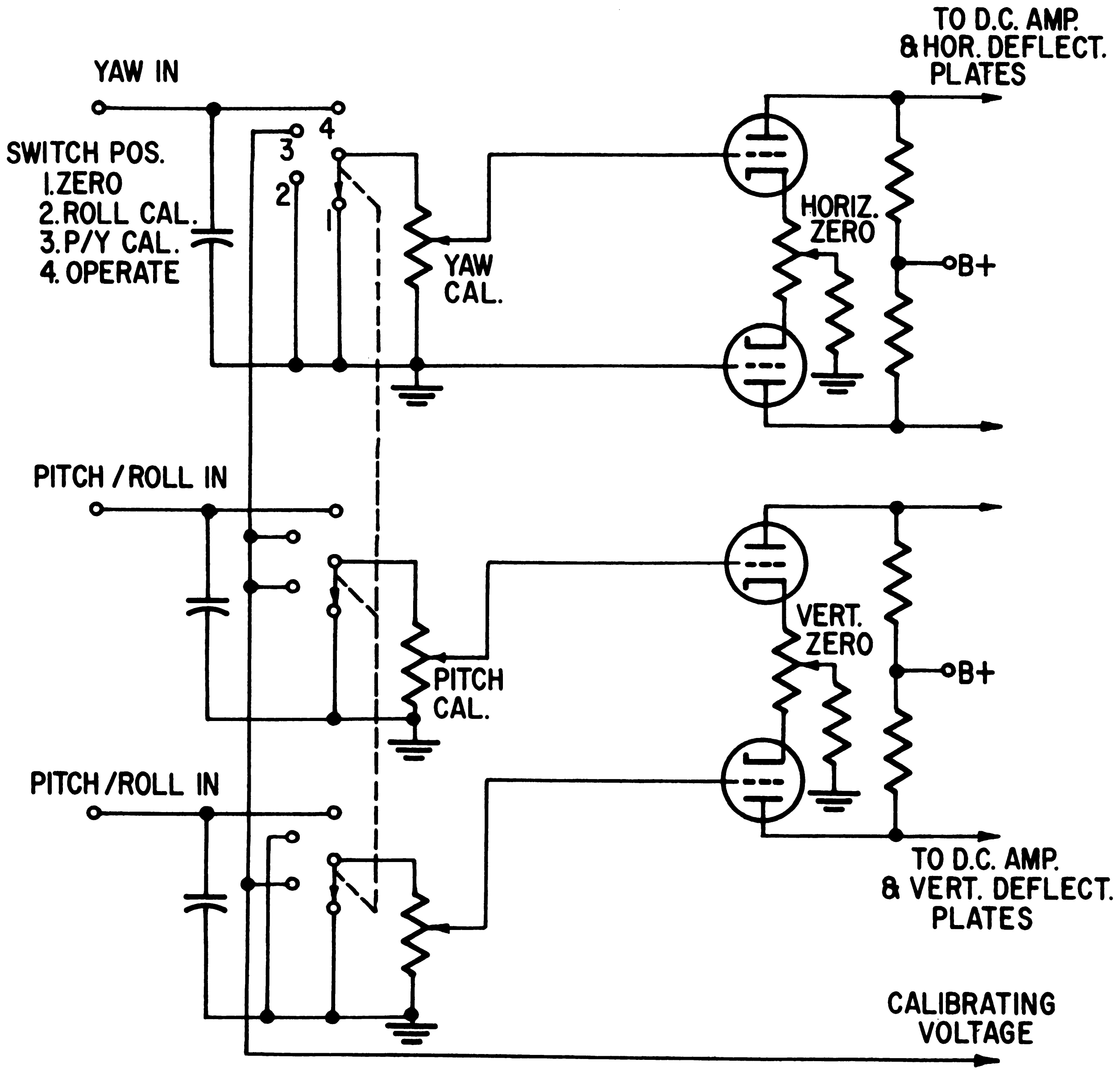


Figure 7-17.—Wing-position indicator circuits.

The vertical amplifier produces a push-pull output which is proportional to the difference of the two input voltages while discriminating strongly against in-phase input signals by means of the common cathode resistors (fig. 7-17). The output of the amplifier is applied directly to the vertical plates of the indicator CRT.

THE SIGNAL GENERATOR

The signal generator, a major section in any manual test equipment, generates microwave signals appropriately modulated for testing missile inflight performance. A representative example is shown in figure 7-18, a block diagram of the generator components included in the test set employed with the guidance-control system previously described. In the following discussions, it is necessary to refer frequently to this diagram and also to the frequency designations in table 7-1.

The principal outputs of the generator are two modulated microwave signals. One, the rear signal, simulates the energy provided directly by the parent aircraft; the other, the

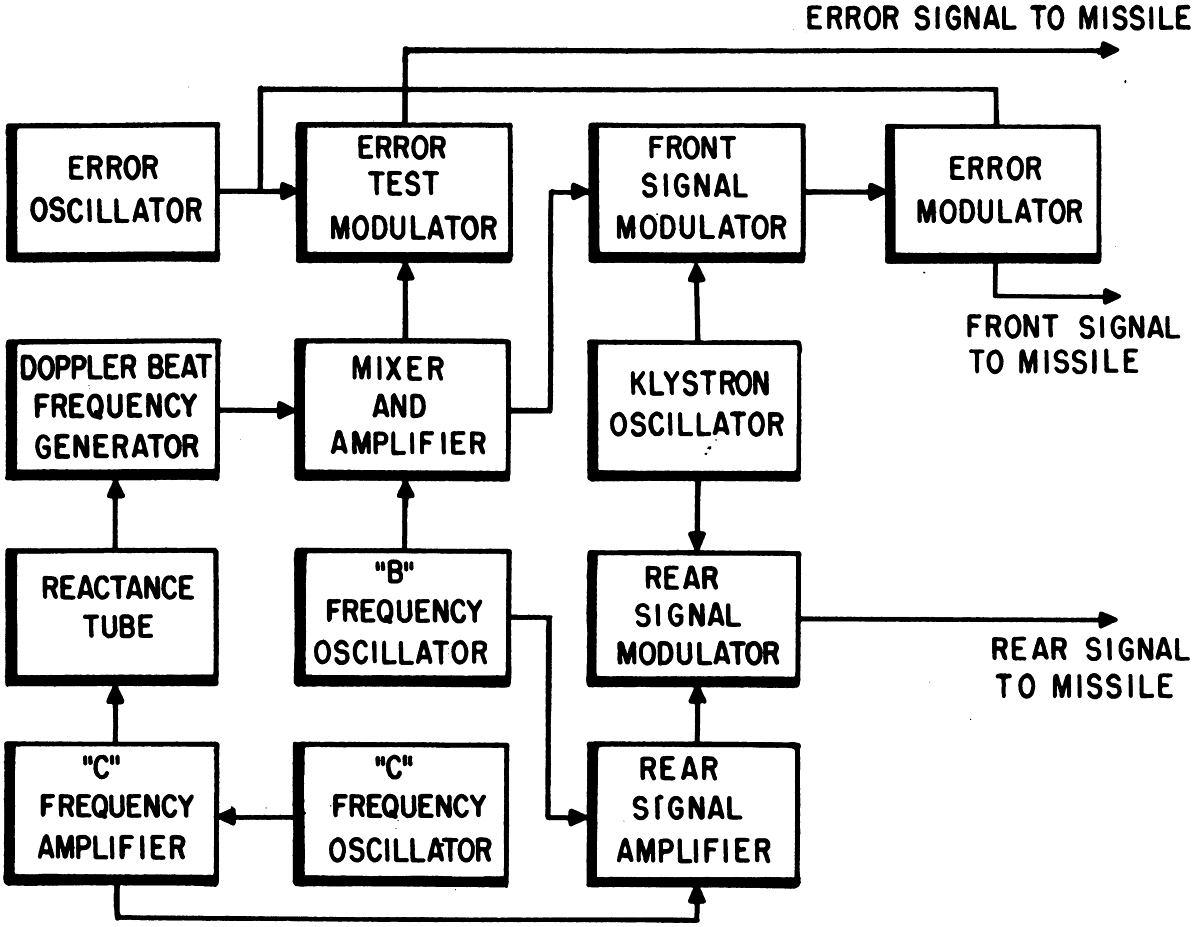


Figure 7-18.—Block diagram of signal generator.

front signal, simulates the energy reflected by the target and received by the front antenna of the missile. In addition, the generator produces an error signal for use in tests of seeker-head dynamics which can be applied as modulation on the front-signal carrier and also directly to the missile via the umbilical plug.

The basic microwave energy from which the rear and front signals are derived is generated by a klystron oscillator. The rear signal is composed of the microwave carrier modulated by frequencies B, B+C, and B-C. In addition to the klystron oscillator, the circuits that develop this signal contain B- and C-frequency oscillators, a C amplifier, a rear-signal amplifier, and a modulator composed of a section of waveguide. The oscillators are conventional R-C and crystal-controlled circuits of the type discussed in *Basic Electronics*, chapter 7. The rear-signal amplifier, the klystron, and the rear-signal modulator are shown in simplified schematic form in figures 7-19 and 7-21.

Rear-Signal Amplifier

The functions performed by the rear-signal amplifier include balanced modulation as well as amplification of the B frequency. Initially, consider the output of the ranging oscillator in figure 7-19 to be zero so that only B signal is applied. In this condition, R_1 serves as a bias resistor common to both grids of the dual triode tube. The latter acts as a push-pull amplifier for B-frequency energy, which is developed at the output, or across the tank circuit containing a ferrite modulation coil in parallel with a tuning capacitor, C_1.

Now, when C-frequency signals are developed across R_1 (fig. 7-19), the grid bias varies at this rate with the result that the B signal is modulated in amplitude; and two sidebands (B+C and B-C) are produced at the output in addition to the B frequency. Since C frequency is applied to the grids of the dual triode in

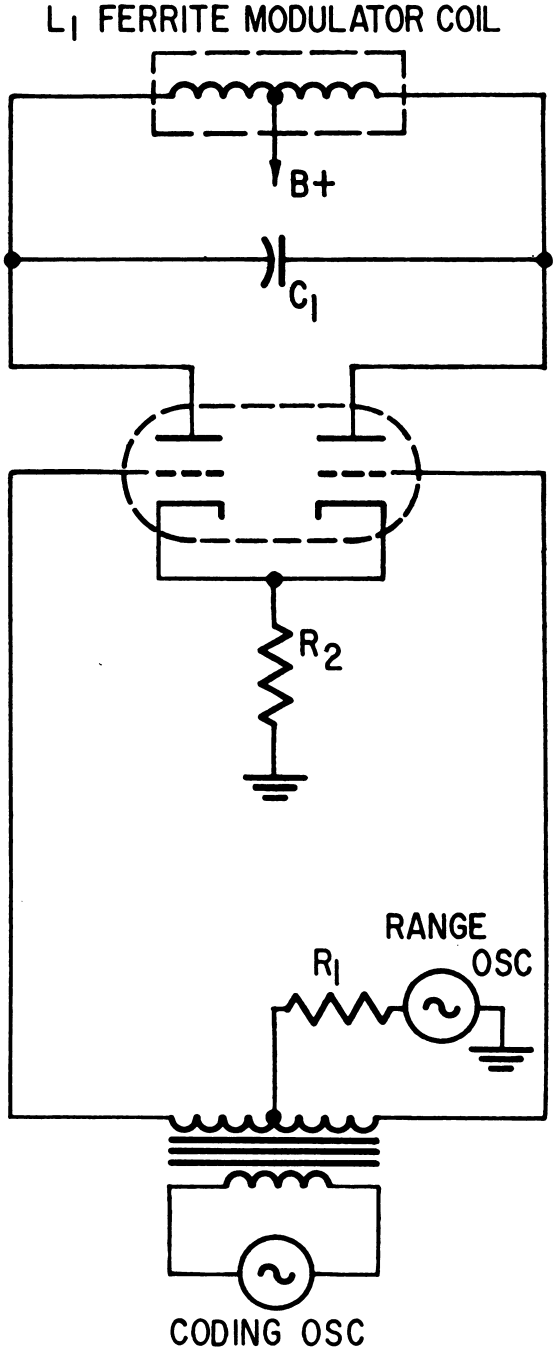


Figure 7-19.—Rear-signal amplifier.

push-push, no output at this frequency is developed. The composite signal from the amplifier provides the input for one section of the rear-signal modulator, which frequency modulates the microwave carrier produced by the klystron oscillator.

Ferrites

The r-f section of the signal generator (fig. 7-18) contains several examples of a special class of microwave circuit elements called ferrites. These consist essentially of small slabs or rods of metallic material with high dielectric constants. When placed within a surrounding magnetic field, either permanent or varying, the material has the property of modifying some fundamental property of applied microwaves such as amplitude, frequency, or phase, depending upon the construction of the element, the nature of the magnetic field, and the frequency of the microwave energy.

The ferrite devices employed in the signal generator include isolators, attenuators, frequency modulators, and differential phase shifters. The basic operation and construction of a phase shifter is indicated in figure 7-20. The purpose of the device is to convert plane polarized waves, represented in (A) to circularly polarized energy, shown in (B). The polarization of the wave is determined by the electric vector, E, which can be considered as being composed of two perpendicular components, E_a and E_b. In the plane wave, these components are in time phase; but if one is shifted in phase by 90 degrees, the wave then becomes circularly polarized.

The required phase shift can be accomplished by the device shown in the lower drawing in figure 7-20. It consists of a slab of teflon, a dielectric material, placed in a circular guide at an angle of 45 degrees relative to the electric vector of the incoming wave. Since one of the components of this vector is oriented at right angles with the slab while the other is parallel with it, the phase angle between the two can be changed by 90 degrees, provided the dielectric material is made with the proper length. Upon emerging from the element, the wave is then circularly polarized and can be considered as containing an electric vector, E, which rotates at a rate corresponding to the frequency. Conversely, a wave with circular polarization can be converted to a plane polarized wave by a similar device in which the slab is placed perpendicular to the position shown in figure 7-20.

Klystron and Rear-Signal Modulator

The klystron source and other r-f units, including the rear-signal modulator, are illustrated in schematic form in (A) of figure 7-21.

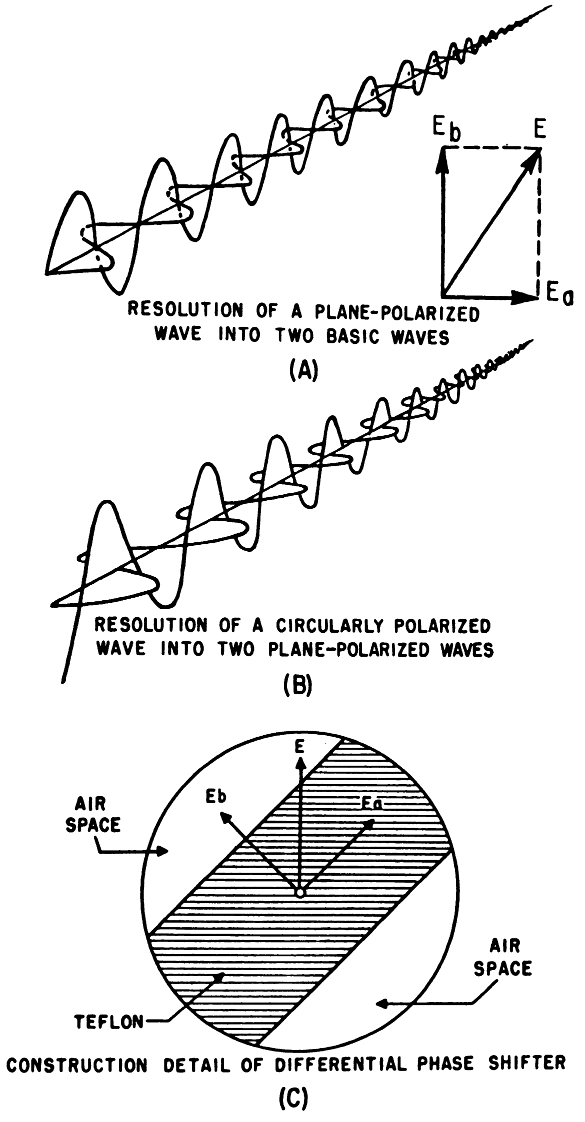


Figure 7-20.—Ferrite differential phase shifter.

The klystron is decoupled from varying load impedances by an isolator, which consists of a ferrite element placed in the field of a permanent magnet. The action of the isolator is essentially that of a unidirectional conductor: it permits waves traveling from the oscillator toward the load to pass practically unimpeded, but strongly attenuates any waves reflected from the load which move toward the klystron.

After passing through the isolator, outgoing signals encounter another ferrite device, a variable attenuator, which reduces them in amplitude by amounts determined by the current following in a surrounding coil. The control current, which can be adjusted by the operator, provides one of several means for adjusting the energy level of the simulated signals to desired values. The isolated, attenuated signals then are applied to a coupler where the energy is divided into three parts and distributed to the rear-signal reference, and front-signal circuits.

The construction of the rear-signal modulator is shown in (B) of figure 7-21. The unit is a length of round waveguide containing three elements which divide the guide into three sections. Section A-B, the input, is a 90-degree differential phase shifter of the type illustrated previously (fig. 7-20). Section B-C, a variable phase shifter, is surrounded by a modulating coil and contains a ferrite rod called a GYRATOR. Section C-D, another 90-degree phase shifter, is similar to the first section except for the position of the teflon slab, which is oriented at right angles with that in the input.

Plane polarized waves from the coupler enter the modulator at section A-B and are converted to circular polarized waves, which then pass into section B-C for modulation. Circular polarization (represented by an electric vector rotating at the r-f frequency) is required because of the inherent characteristics of the ferrite gyrator, the modulating device. This element has the ability to control the rate of rotation of the electric component of the wave when a magnetic field is present in the ferrite material. The amount and direction of the rotary effect it produces are dependent upon the amplitude and polarity of the magnetic field; and if the latter varies sinusoidally, the r-f rotation varies accordingly. The variations in rotation produced by the gyrator element are equivalent to changes in frequency; and by this action, the ferrite rod frequency-modulates the microwave carrier in accordance with currents flowing in the surrounding modulating coil. The modulating signal current is supplied by the rear-signal amplifier.

The modulated waves then enter section C-D (fig. 7-21) where another phase shift occurs which restores plane polarization. The plane polarized waves are then frequency modulated with the information required in the rear signal and are applied to a rectangular waveguide at the output.

Front-Signal Circuits

In addition to the rear signal, the generator shown in figure 7-18 also develops a front signal

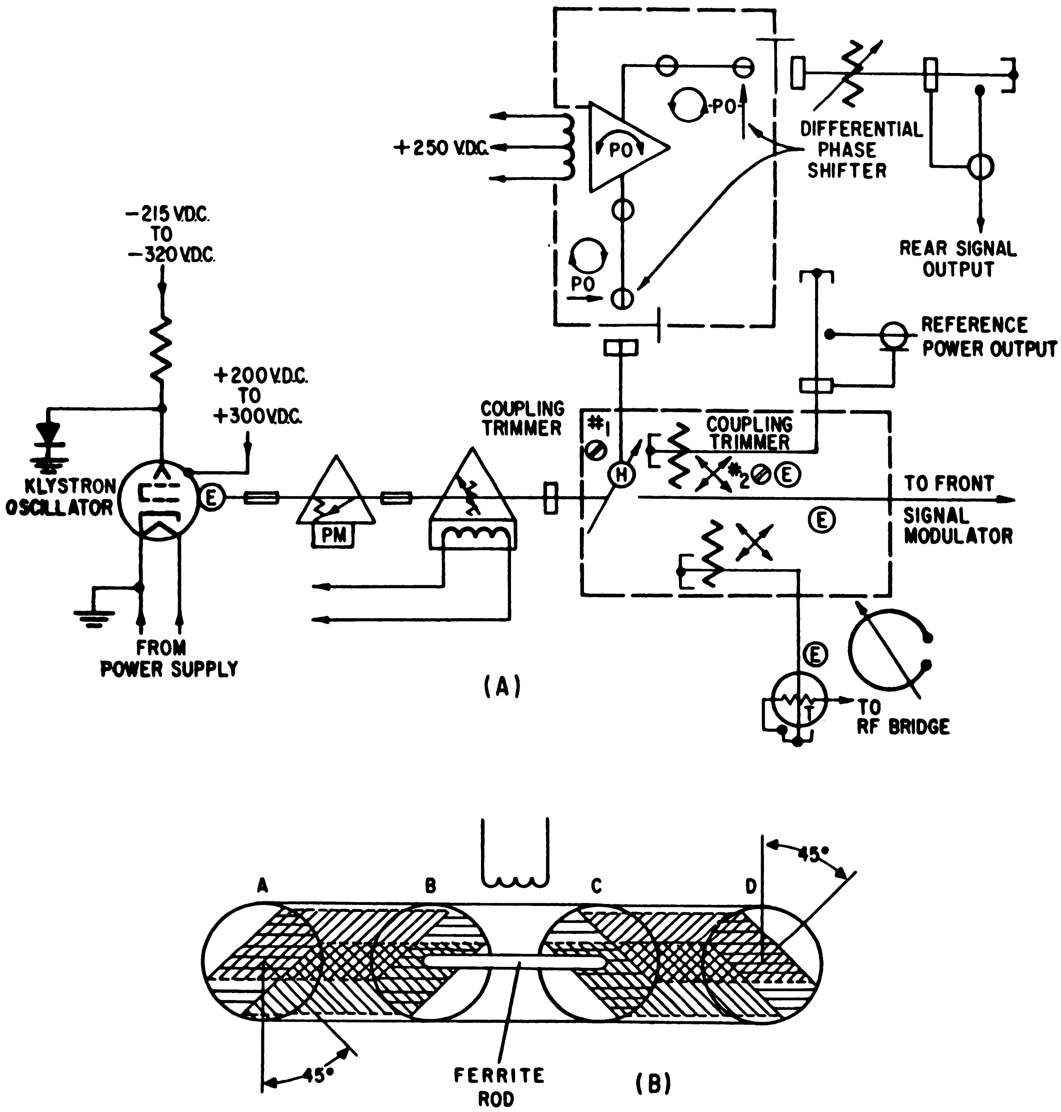


Figure 7-21.—(A) Klystron and associated units; (B) construction of the rear-signal modulator.

which simulates energy reflected from the target to the missile. The front-signal carrier differs in frequency from the rear-signal carrier by selectable Doppler frequencies, which correspond to various velocities of the missile relative to the target. The generator produces the front signal by first amplitude modulating the microwave carrier, resulting in the production of two sidebands, and then rejecting the carrier and lower sideband. The remaining sideband signal then becomes a new carrier which differs from the rear-signal frequency by an amount equal to the selected Doppler.

The front signal is also frequency modulated at the C-ranging frequency; and it may be amplitude modulated at a frequency slightly below D, the electrical scanning rate of the missile antenna. With D modulation, the front signal is interpreted by the missile as being returned from a target rotating in a circular path around the boresight axis; and as a result, the missile wings respond with essentially sinusoidal deflections.

The Doppler component is developed by heterodyning the output of the B oscillator with that of a frequency-modulated, beat-frequency oscillator. The latter circuit, which contains

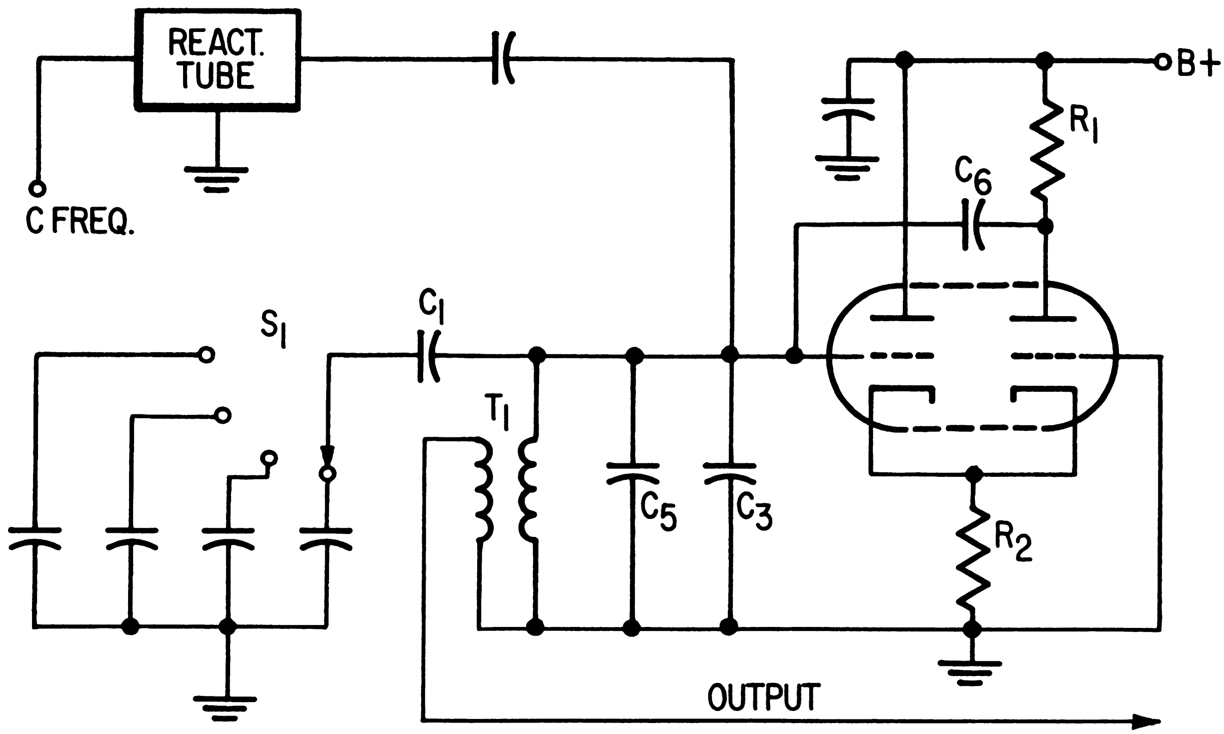


Figure 7-22.—Doppler beat-frequency generator.

a reactance modulator, produces several different outputs, any one of which can be selected by the operator to simulate different missile closing speeds.

The reactance modulator is of the type discussed in *Basic Electronics*, chapter 8, and is connected with the beat-frequency oscillator as shown in figure 7-22. The oscillator tube, the left-hand section of the dual triode, is followed by a grounded-grid, cathode-coupled amplifier, the right-hand section. The oscillator is connected to an L-C circuit in which the inductance consists of the primary of transformer T_1 and the capacitance is made up of C_1, C_3, C_5, and the capacitor selected by the setting of the switch. The feedback loop runs from the left of the triode through the common cathode resistor R_2 and is completed through C_6 back to the grid of the left-tube section.

As indicated in figure 7-22, the reactance tube is effectively in parallel with the primary of T_1 and hence, represents a part of the total inductance in the resonant tank circuit of the oscillator. The grid of the reactance tube receives inputs at C frequency; this causes corresponding variations in the tank inductance; and as a result, the output of the beat-frequency oscillator is frequency modulated with ranging information. This output is then fed to a pair of mixers (fig. 7-18) where it is combined with signals from the B coding oscillator.

The operation of the front-signal modulator requires two Doppler signals identical in frequency but differing in phase by 90 degrees. To produce these, the two mixer tubes are fed B signals in quadrature and simultaneously receive beat-frequency signals in phase. The result is an output in each tube which contains, in addition to other frequencies, a component at the difference of the two applied frequencies. The difference components are filtered out and become the Doppler outputs, which differ by the required 90 degrees and which are then applied to the modulator.

The front-signal modulator accepts signals from the Doppler circuits and uses them to produce a single-sideband, suppressed-carrier output, which is routed to the seeker-head assembly in the missile. This signal simulates the echoes received in flight by the front antenna and differs from the rear signal in frequency by the amount of Doppler frequency shift involved.

A conventional circuit for producing suppressed-carrier, single-sideband output

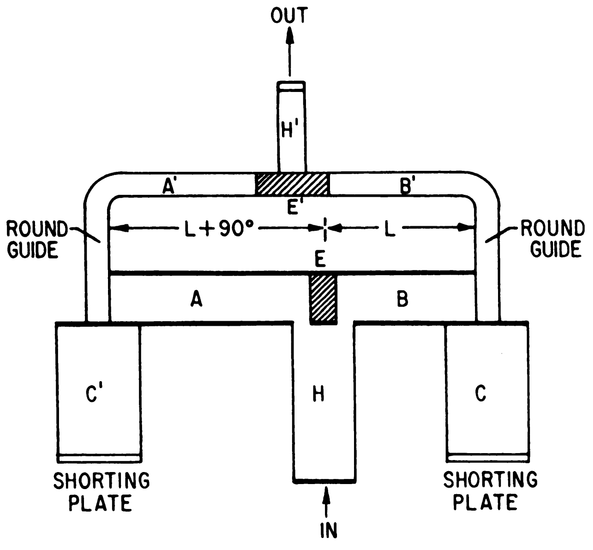


Figure 7-23.—Front-signal modulator.

contains two balanced modulators. The two carrier waves applied to them differ in phase by 90 degrees; and the modulating signals are also displaced by this amount. These same conditions are present in the modulator shown in figure 7-23, except that instead of conventional elements such as tubes, the unit contains ferrite modulating devices of the type employed in the rear-signal modulator. The ferrite modulators, or gyrators, together with the associated modulating coils, are mounted in the assemblies marked C and C' in the figure. The suppression of the carrier and the lower sideband result from the physical and electrical properties of the waveguide arms and also of the hybrid tee junctions contained in the input and output sections of the modulator.

Microwave energy enters the modulator (fig. 7-23) at the input (H) arm of the input hybrid tee and divides equally into arms A and B. Arm A is longer than arm B by a quarter wavelength. Thus, the r-f signals entering the modulators (C and C') are in phase quadrature, so that the first requirement for single-sideband, suppressed-carrier production is met. In the absence of modulation, the carrier is reflected from the shorting plates at the guide ends and re-enters arms A and B. Upon reaching the input tee, the two components are 180 degrees out of phase as a result of the round-trip passage through the unequal arms. This phase relation is the condition necessary for the reflected energy to propagate through the E arm of the hybrid tee which leads to a dissipative load, where any difference energy resulting from incomplete cancellation of the waves is dissipated.

When quadrature modulating signals are applied, sideband components are produced which exit toward the output arms (A' and B', fig. 7-23). The latter arms are of equal length. Upon arriving at the output hybrid tee, the signals combine in such a way that the upper sidebands are in phase while the lower sidebands are in phase opposition. The upper sidebands are of the proper phase to pass into the output arm (H') and hence become the output signal; the lower sidebands combine in the proper phase to enter the load arm, where the energy is dissipated by the load device.

In addition to the Doppler component, the signal generator (fig. 7-18) provides an error-simulating function which permits the front signal to be modulated with D frequency. This special modulation simulates a rotating target and is employed in tests of the seeker head. A variable attenuator is included in the front section which permits the output to be adjusted to the desired level.

GENERAL TEST PROCEDURE AND TYPICAL INDICATIONS

The checkout procedure used with the test equipment discussed above is relatively simple and can be performed quickly and efficiently by a reasonably well-trained operator. Appropriate meters, lamps, and cathode-ray displays show the results of the various checks on an accept-reject basis.

Among the major checks that involve meter indications are front and rear sensitivity and autotune functioning. The test of the fuzing circuits is monitored by means of a lamp.

Sensitivity and autotune tests are checks on the reception range of the missile and proper response insures adequate performance of the vehicle at maximum range as well as close in to the parent aircraft. These are performed by manual methods in which the operator adjusts variable attenuators in the r-f section of the signal generator and notes corresponding readings of meters in the AFC and recycle circuits.

To check rear-system sensitivity and autotune action, the level of the simulated rear signal is reduced almost to zero. As a result, the missile klystron loses lock and goes into the search function under control of the AFC circuit. The operator then decreases the

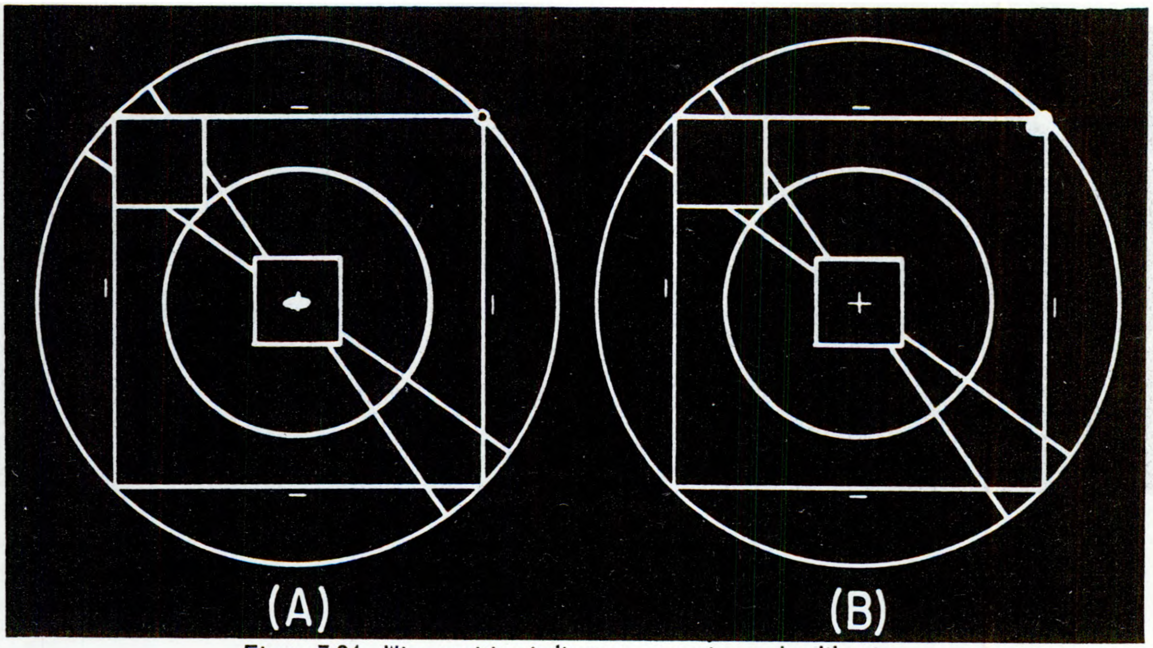


Figure 7-24.—Wing-position indicator: centering and calibration.

attenuation, thereby applying larger input signals; the klystron again locks on; and the AFC voltage approaches zero. During these operations, the data for the rear-system sensitivity as well as the indications of the autotune action are given by the readings of the AFC meter.

The check on the front-system sensitivity is similar. With normal rear signal present, the applied front signal is attenuated until the speedgate in the missile develops a recycle voltage. The meter in the recycle circuit then provides the information for determining the sensitivity of the circuits under test.

The missile fuzing circuits are tested by pressing a special "detonate" switch which shifts the Doppler frequency downward and provides a trigger for initiating the control action. Proper operation of the control circuit is indicated by a lamp on the test console panel.

A second class of major missile checks requires the use of the wing-position indicator, which must first be centered and calibrated by the operator. When properly centered, the vertical and horizontal deflection circuits in the unit operate with equal gains; and with zero input, the spot on the face of the cathode-ray tube is situated as in (A) of figure 7-24. Then, with the calibrating voltage applied to the input circuits, the spot should move from the center of the scope to the upper right-hand corner of the tolerance mask, as in (B) of the same figure.

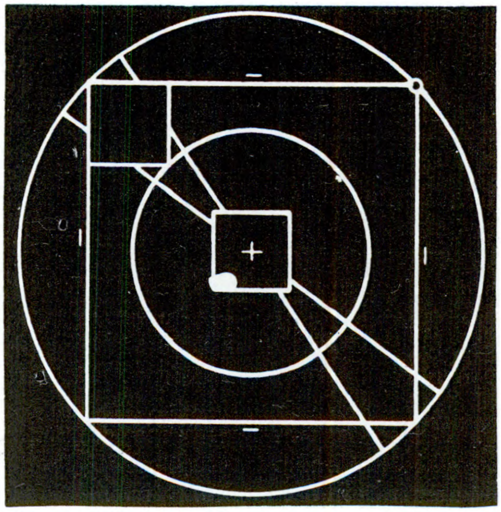


Figure 7-25.—Head drift in-tolerance indication.

The check on seeker-head drift is performed by injecting a zero-error-modulation signal into the missile which simulates a target on boresight. The indicator display then shows the ability of the head antenna to remain within specified limits. If the balance and drift are within tolerance, the spot on the CRT mask remains within the small square (fig. 7-25). If the spot is out of tolerance, external adjustments of the integrator section may provide sufficient compensation to meet requirements, but if not, the missile is a reject.

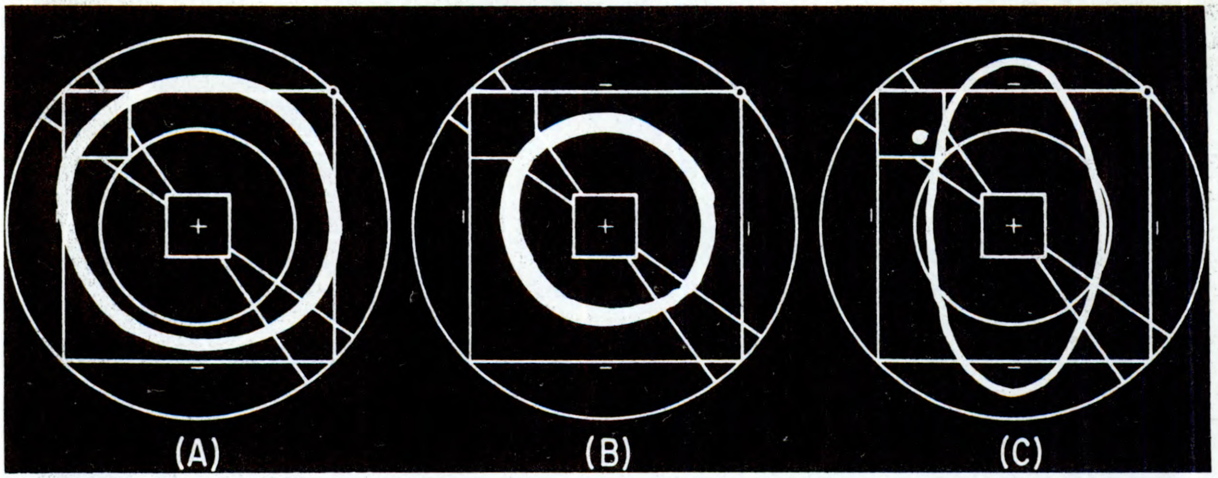


Figure 7-26.—Error sensitivity test indications.

After head drift has been determined as being within tolerance limits, error modulation is applied to the front signal which is interpreted by the missile as a target rotating around the boresight line. The wings then respond with sinusoidal displacements differing in phase by 90 degrees. The pickoff potentiometers in the wing hubs develop equal quadrature voltages; and when these are applied to the plates of the position indicator, the result is a circular Lissajous pattern.

The diameter of the circle is dependent upon error amplitude, three conditions of which are shown in figure 7-26. An in-tolerance missile responding properly to the injected signal is indicated in (A). Part (B) shows the deflection pattern for the same test, but with a missile in which the gain is marginal, or just above the low limits. Part (C) indicates that the missile has normal gain in one channel but low gain in the other and therefore must be classed as a reject.

The ability of the missile to compensate for different altitudes is also checked by observing the diameter of the response circle as different simulated altitudes are switched in. At higher simulated altitudes, greater wing deflections are required for correction of a given error and thus, as altitude increases, the circle diameter should also increase.

Monitoring of the control instruments is also a function of the wing position indicator. First, the steady-state wing deflection is measured for a known accelerometer output. The missile is then rolled 45 degrees and the wing deflections for both channels are determined. For a steady-state condition (in which the accelerometer mass is displaced by gravity rather than by inertial forces) the wing deflection which results is constant and produces a display of the type shown in figure 7-27.

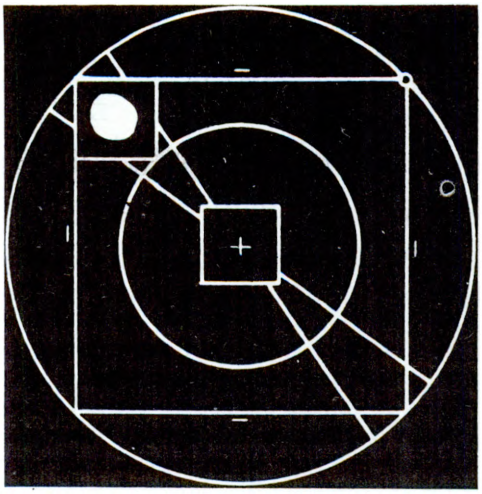


Figure 7-27.—Accelerometer check.

The rate gyros of the missile are tested for phase and amplitude response by deflecting the missile on the test stand against a spring restraint and then releasing it. This subjects the rate gyros to damped sinusoidal mechanical excitation and results in the type of indication shown in figure 7-28.

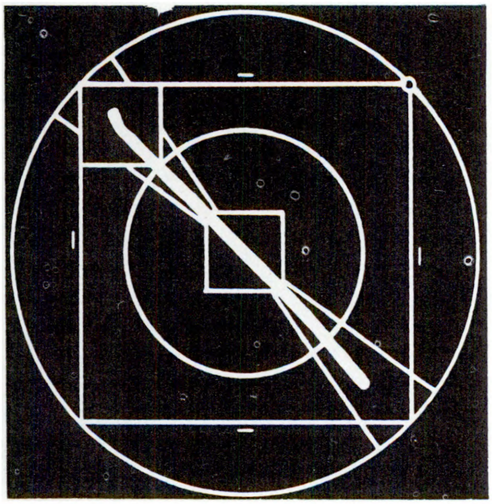


Figure 7-28.—Rate gyro response check.

The method of monitoring test results by means of cathode-ray displays is typical of consolidated equipments, which are designed for testing more than one missile of a particular family. The tester, which contains certain basic components common to all checks, is modified for a specific missile by substitution of the necessary special devices, such as signal-simulating units or radiators. The wing position indicator can then be modified for the desired checks by attaching a mask containing the required tolerance markings.

COMPARISON OF EQUIPMENT TYPES

Manual test equipment of the type discussed above has certain general advantages and disadvantages when compared with automatic testers. Manual sets have somewhat greater capability for exact analysis of malfunctions and for rapid location of faults. In the event of a reject, the operator can repeat various test steps and run isolated checks to locate the trouble more precisely. Most manual equipment contains fewer moving mechanical parts than comparable automatic devices and hence require less maintenance and repair.

The major disadvantage of the manual tester lies in the increased possibility of passing bad missiles, particularly when the performance of the system is near the dividing line between accept and reject. This is a result of the greater chance of operator error arising from the fact that much of the data are given by meters or by oscilloscope displays rather than by simple lamp indications as in the case of the completely automatic tester.

Manual equipment requires more time for comparable amounts of testing since the results of each test step must be read out, interpreted, and in some cases, entered in a log or other type of record. In addition, the manual device requires a higher degree of training on the part of the operator, who not only must be skilled in the use of the test set but must also have a good working knowledge of the functioning of the missile as well.

QUIZ

1. A missile GO, NO-GO system of testing requires
   a. no participation on the part of the operator
   b. that the test set first be run through a self-check
   c. the operator to perform the same function as on a semiautomatic tester
   d. extensive interpretation of test results by the operator.

2. The GO, NO-GO test set sequence timer (fig. 7-1) switch timing must be accurate to within 0.25 seconds. In case of any discrepancy, the
   a. cam rings must be reset
   b. cam microswitches must be repositioned
   c. sequence timing motor should be recalibrated
   d. factory representative should be notified

3. Correlation of the GO, NO-GO test set cam and switch numbers with the time intervals of the various test steps is checked by means of
   a. a revolution counter
   b. automatic self-checks
   c. trouble indicating lights
   d. a sequence timing chart

4. The rotary programing switch (fig. 7-3)
   a. selects and feeds input signals to the missile
   b. applies missile outputs to monitoring circuits
   c. stops programing action if a missile check is out of tolerance
   d. all of the above

5. The ratchet wheel (fig. 7-4) causes the wiper to be repositioned on the next contact by
   a. action of the detent
   b. the armature when it lifts the pawl
   c. action of the driving spring and pawl
   d. the magnet when it is energized

6. Any backward movement of the wiper assembly (fig. 7-4) is prevented by the
   a. detent
   b. pawl
   c. driving spring
   d. armature

7. The speed of the motor in the recycle timer (fig. 7-6) can be varied
   a. when the speed control potentiometer is bypassed
   b. during the first two steps
   c. during steps 2 through 7 inclusive
   d. during steps 3 through 7 inclusive

8. Referring to figure 7-8 (A), when the element under test is inserted in the transistor circuit between base and ground
   a. collector current will energize the relay if the element has abnormally high resistance
   b. collector current will not energize the relay if the element is less than a certain critical value
   c. resistance values of the element will be monitored by a light
   d. collector current will energize the relay if the element is open

9. The operation of the monitor (fig. 7-9) depends largely on the
   a. regulation of the 28-volt, d-c supply source
   b. resistance of the indicator light circuit
   c. ability of the transistors to conduct with an open base circuit
   d. ability of a Zener diode to conduct in a backward direction

10. The tolerance limit of the automatic voltage monitoring circuit (fig. 7-10) is determined primarily by the
    a. setting of the monitor level set
    b. bridge rectifier balance
    c. amplitude of the 400-cycle input
    d. frequency of the chopper

11. The automatic voltage monitoring circuit (fig. 7-10) sums the input voltages in a
    a. two-stage amplifier
    b. 400-cycle chopper
    c. bridge rectifier
    d. T-network

12. The automatic system of missile testing
    a. makes electrical and mechanical connections
    b. selects tests to be performed by the equipment
    c. requires manual selection of the various tests
    d. requires interpretation of the results by the operator

13. During search operation, the local oscillator of the speedgate is shifted in frequency (fig. 7-13) by
    a. the output of the discriminator
    b. the D frequency
    c. sweep generators
    d. the B frequency

14. In the coherency check performed by the speedgate, the output of the balanced modulator must contain
    a. A frequency
    b. B frequency
    c. C frequency
    d. D frequency

15. The output of the spin detector represents
    a. direction and distance of target from boresight axis
    b. electrical scan rate of antenna
    c. angles at which target is spinning
    d. closing velocity of target

16. Teflon units inserted into waveguides can be used to
    a. attenuate signals
    b. block incoming waves
    c. change the polarization of waves
    d. accomplish all of the above

17. Action of the trislot antenna provides
    a. target speed information relative to closing velocity
    b. frequency modulation of the incoming signal
    c. target angle information with reference to boresight line
    d. polarization to the incoming signal

18. The front signal modulator produces
    a. an output to simulate coding information
    b. only the Doppler frequency
    c. a carrier output only
    d. a single-sideband, suppressed-carrier output

19. Referring to figure 7-15, a negative input to the grid of V_1 causes
    a. K_1 to energize and CR_1 to conduct
    b. K_2 to energize and CR_2 to conduct
    c. K_1 to energize and CR_2 to conduct
    d. K_2 to energize and CR_1 to conduct

20. In reference to figure 7-14, R_1 serves to
    a. set the normal differential current through the meter
    b. set the operating level of the tube
    c. prevent degeneration in the cathode circuit
    d. stabilize the plate voltage

21. With a simulated rotating target applied to a missile, the response on a Wing Position Indicator is a straight line instead of a circle. This indicates
    a. a lack of a roll component
    b. that accelerometer gain is too high
    c. a lack of a pitch component
    d. a quadrature relationship of wing potentiometer voltages

CHAPTER 8
ELECTRONIC COMPONENT TESTING

Systems checks, performed with the type of equipment discussed in the preceding chapter, belong to one of the two principal classes of missile tests. The other class includes tests performed on specific components rather than on major systems or subsystems.

Some forms of systems testing is required with practically all missiles. Component testing, though not applied extensively in air-launched missiles, is of importance to the GF to give him broader technical training and background in the missile field. In addition, the material in this chapter serves to introduce later chapters which deal with test procedures involving more complex components, such as servomechanisms and gyroscopes.

The systems tester gives overall, highspeed, confidence checkout of items such as guidance and control systems or the electrical power section. Component test sets check particular assemblies prior to installation in the missile or when these are found to contain malfunctioning circuits during systems testing.

The type of information required for component testing, together with the equipment and procedures employed, are the subject areas of this and the three following chapters. This chapter concerns electronic guidance and control units. The subsequent chapters deal with the more mechanical elements noted above and with electronic power-supply packages.

The electronic components of a typical beam-rider missile are used as examples in the following pages. Before beginning this chapter, the trainee is requested to review the introductory treatment of this system as given in chapter 5, *GF 3 & 2,* which describes the principal features of the missile and its performance in the two phases of flight, automatic-pilot and beam-guidance operation.

Beam-Rider Signal Flow

Guidance and control of the beam-rider missile are accomplished by the response of the missile-borne components to radar signals received from the launching aircraft. The essential features of the system are indicated in figure 8-1. In (A), the missile is assumed to be displaced from the center of the beam scan pattern and flying along a line to the right and above the desired course. The interconnection of the missile components is shown in (B); and with each block, input and output waveforms are included which indicate the signals developed as a result of the assumed position of the missile. The operation of the system is such that with these signals present, the control surfaces are moved to steer the missile down and to the left until it reaches the center of the beam pattern. (Blocks drawn with solid lines indicate the electronic components discussed in this chapter; blocks in dashed lines are non-electric units, the testing of which is described in other chapters of this course.)

Signal flow in the system begins when the r-f radar pulses transmitted by the aircraft radar are received by antennas mounted in the tail section. The paired r-f pulses differ in time spacing according to their positions on the scanning circle of the beam. Thus, a pulse pair with one-microsecond spacing is situated to constitute a fly-down (F/D) signal; while fly-up (F/U) pulses are separated by two microseconds; and fly-left (F/L) and fly-right (F/R) by three and four microseconds, respectively, as indicated in (A) of figure 8-1.

When received by the missile tail-section antennas, the pulse pairs vary in relative amplitude according to the position of the missile with respect to the center of the beam pattern. The r-f carrier is removed by detectors in the tail section; and the output of the component consists of d-c pulses with voltage values proportional to the corresponding amplitudes of the received guidance signals.

The d-c pulses are applied to the guidance receiver, which develops four negative output voltages; one for each of the input pulse pairs. The magnitude of each output is directly proportional to that of the corresponding input so

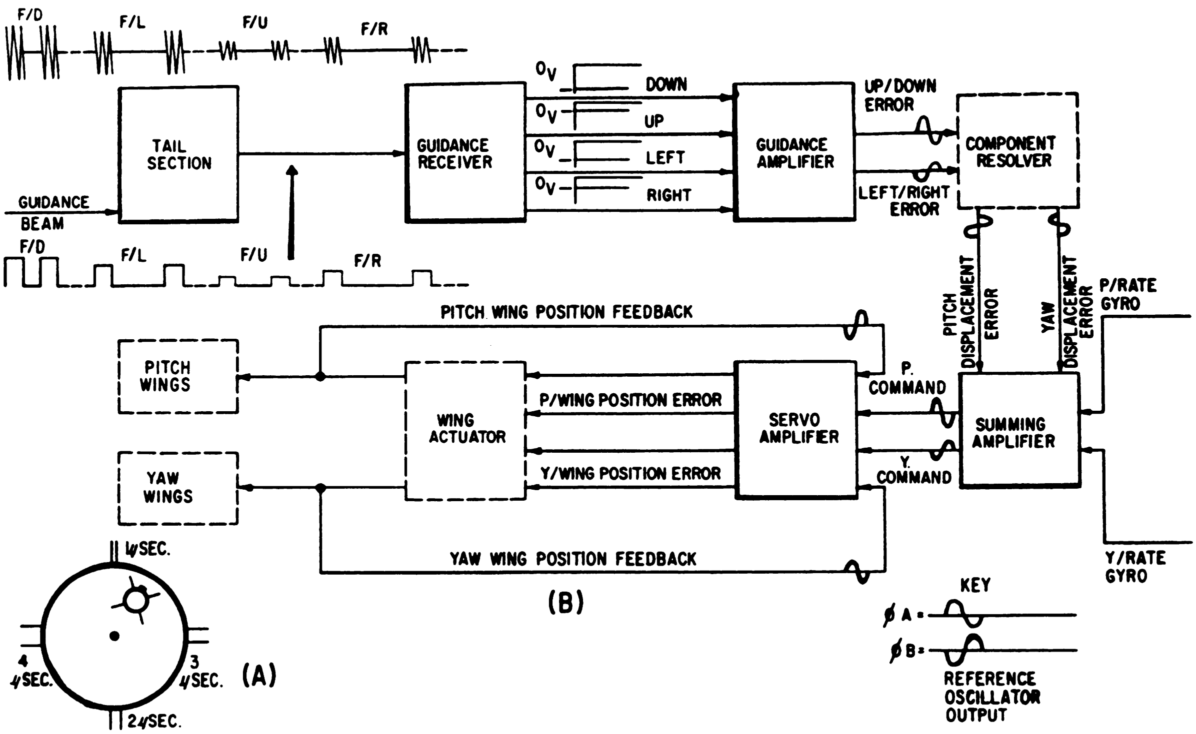


Figure 8-1.—Signal flow in the beam-rider system.

that the four voltages represent up, down, left, and right error values.

This information is fed to the guidance amplifier, which combines voltages representing opposite displacements (up with down, left with right) to produce two resultants, each of which is used to modulate the output of a reference oscillator. Two a-c signals are thus produced, the up-down and left-right errors indicated as sine waves in (B) of figure 8-1. These contain the error information in terms of amplitude and phase. For example, the amplitude of the up-down signal is proportional to the difference in magnitude of the d-c up and down voltages, while the phase (A or B) is dependent upon which d-c input is greater in voltage. The right-left error signal is determined in a similar way.

The component resolver converts the up-down and left-right errors into two signals which contain the same information but expressed with respect to a different coordinate axis, that formed by the pitch and yaw wings of the missile. (This process of conversion is illustrated in *GF 3 & 2,* chapter 5.)

The outputs of the component resolver are combined with voltages from the pitch and yaw rate instruments. This combination takes place in the summing amplifier, the outputs of which are called pitch and yaw command signals.

The servo amplifier receives the a-c command signals and responds by developing d-c wing-position error voltages. These actuate solenoids controlling the valves of the hydraulic wing units, thereby causing the missile wings to move in the directions necessary to steer the vehicle back to beam center. As the wings move, a-c feedback voltages are developed which vary in amplitude with wing position. The feedback voltages are combined with the pitch and yaw command signals in phase opposition, so that when the latter signals are canceled by feedback, the wings come to rest.

Component Functions and Related Test Equipment

Each electronic component in the system described in the preceding section is tested and adjusted by means of specialized test sets and the appropriate standard measuring instruments. The specialized tester is designed in each case to check the component in the operating condition. Hence, to understand the type of equipment required and the tests performed, it is necessary to consider first the principal functions of the various units. In this section, the components drawn in solid blocks in figure 8-1 are discussed in the order of signal sequence; and with each, except one, the major items of test equipment are listed. This one is used as a representative example, and the test set and checkout procedures employed with it are described in greater detail in the final two sections of the chapter.

THE TAIL SECTION

The principal functions of the tail section assembly are reception of the guidance radar pulses, demodulation of the signals, and application of the resulting video pulses to the following stage, the guidance receiver.

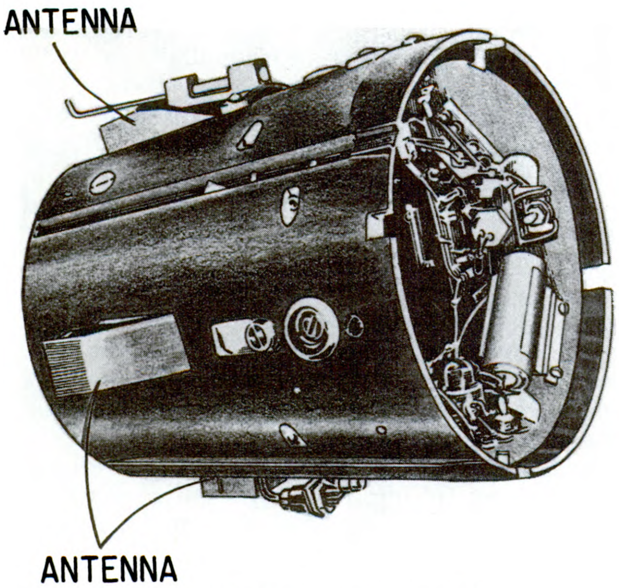


Figure 8-2.—Tail section assembly.

The guidance pulses are received by four open-ended waveguide sections, which operate as directional antennas (fig. 8-2) having maximum sensitivity toward the rear and along the line of the missile longitudinal axis. Two antennas of the type shown would be sufficient to insure proper polarization with respect to the radar beam. However, the use of two pairs insures reception in case one pair is shaded by the tail fins or the body of the missile.

Each tail-section antenna is terminated in a short circuit and contains a crystal unit mounted at a distance of one-quarter wavelength from the shorted end. The crystal in each section operates in conjunction with stray capacitance and lead inductance, thereby forming a diode detector circuit with filter. This circuit rectifies the incoming microwave signals, filters out the carrier frequency, and produces video-frequency pulses, which form the output of the component.

The output terminals of the four crystal circuits are connected in parallel. The video signals form each are fed to a cathode-follower stage called a preamplifier, which serves to match the high-impedance crystal circuits to the low-impedance input of a coaxial cable. The latter couples the video pulses to the guidance receiver.

In order to protect the crystal units from high-powered microwave pulses when the missile is near the aircraft transmitter, a TR tube is mounted in each section of the antenna system between the receiving end and the crystal. The purpose of the TR tube is to short out pulses with magnitudes great enough to damage the crystals and to pass smaller pulses without change.

The principal items of component test equipment for the tail section are an r-f pulse generator and an oscilloscope. The generator produces test inputs of the type received in operation which can be varied in amplitude to simulate signal conditions occurring in flight. The oscilloscope serves as an output indicator for evaluating the quality of the video waveforms and for measuring their amplitudes. A spectrum analyzer is also used as a tuning indicator with tail sections that contain tunable TR tubes. These are usually adjusted during preflight checks to insure that the TR cavities are correctly tuned to the frequency of the aircraft radar.

GUIDANCE RECEIVER

The major functions of the guidance receiver are three in number: amplification, demodulation, and correction of the signal voltages for

the effects of increasing missile range. Amplification is accomplished in a video strip containing eight stages—six video amplifiers and two cathode followers. The demodulator consists of a pulse stretching circuit, a coincidence circuit, and a filter for each pair of guidance pulses. (A demodulator of this type is illustrated in chapter 5, *GF 3 & 2.*)

Signal correction for increasing range is effected in two ways. The first is by automatic gain control (AGC) applied to the first three video amplifiers. The second correction is made by a special circuit supplying modulation-control voltage (MCV) at the grid of the fifth video tube. The AGC circuits are similar to those discussed in chapter 12, *Basic Electronics*, NavPers 10087. The purpose of the MCV circuit and its operation are discussed in the following paragraphs.

Video Amplifiers and Cathode Followers

The first four video amplifiers are conventional circuits. The final four stages and the MCV circuit are shown in simplified schematic form in figure 8-3. The fifth video amplifier, V_2, requires a signal of large amplitude so that MCV can be introduced at this point. The last three stages supply the demodulator with high-amplitude signals developed by the use of regenerative feedback; thereby providing much greater gain than would be possible if the low supply voltages and small tubes employed were connected in a conventional circuit. (The demodulator requires large signal amplitude so that voltage variations resulting from contact potentials and inequalities in tube action will form only small parts of the demodulated output.)

The circuit that supplies the large video signals required consists essentially of an amplifier and two cathode followers (fig. 8-3). The significant feature is the feedback from the output of the second cathode follower, V_5, through C_1 to the point between the load resistors, R_2 and R_3, of the amplifier. The positive signal voltage across the cathode-follower load resistor, R_4, is fed back regeneratively to effectively increase the plate voltage of the amplifier. The feedback ratio is less than one, since the gain of a cathode follower is less than unity; however, the regenerative action is sufficiently strong that the gain of the amplifier approaches the amplification factor of the tube. The circuit is stabilized by degenerative feedback applied to the amplifier grid through resistor R_1.

Modulation Control Voltage (MCV)

To understand the action of the MCV circuit (fig. 8-3), it is necessary to consider two effects on the guidance signals as the missile range increases. First, as the missile recedes from the aircraft transmitter, the strength of the signals it receives diminishes by a factor of $1/D^2$ where D is the range. Second, the percentage of modulation of the error signals decreases with increasing range. The latter effect occurs because the error signal received is a function of the angle subtended by the missile at the parent aircraft as well as a function of the distance of the missile from the beam axis. As the range increases, the angle in question decreases with a corresponding decrease in modulation percentage even though the error distance (measured from the missile to beam axis) remains constant.

It is next desirable to define the meaning of the term modulation percentage when applied to the beam-rider error signals. The magnitude of the signals in the up-down and left-right channels of the control system depends upon the relative magnitudes of the opposing F/U and F/D or F/L and F/R signals received. The modulation of the error signals is defined as the ratio A-B/A+B, where A and B are the magnitudes of the opposing pulses. The decrease in this ratio with range can be illustrated by means of figure 8-4.

At range D_1, the modulation percentage is large because of the large angle subtended (X); while at range D_2, although the error distance is the same, the modulation percentage is smaller due to the smaller angle, Y. Therefore, in order to steer the missile with minimum error distance, the modulation percentage must remain constant regardless of increasing range. To accomplish this, it is increased artificially by the MCV circuit during missile flight. In addition, the gain of the receiver must also be increased as range increases so that the signal level remains constant.

The desired increase in modulation is effected by subtracting equal amounts of voltage from each pair of opposing signals by the biasing action of the modulation control tube (associated with the video amplifiers in the guidance receiver). The bias voltage employed is an exponentially rising function of time; hence the amount subtracted from the signals increases with missile flight time, and therefore with range. The action of the AGC circuits

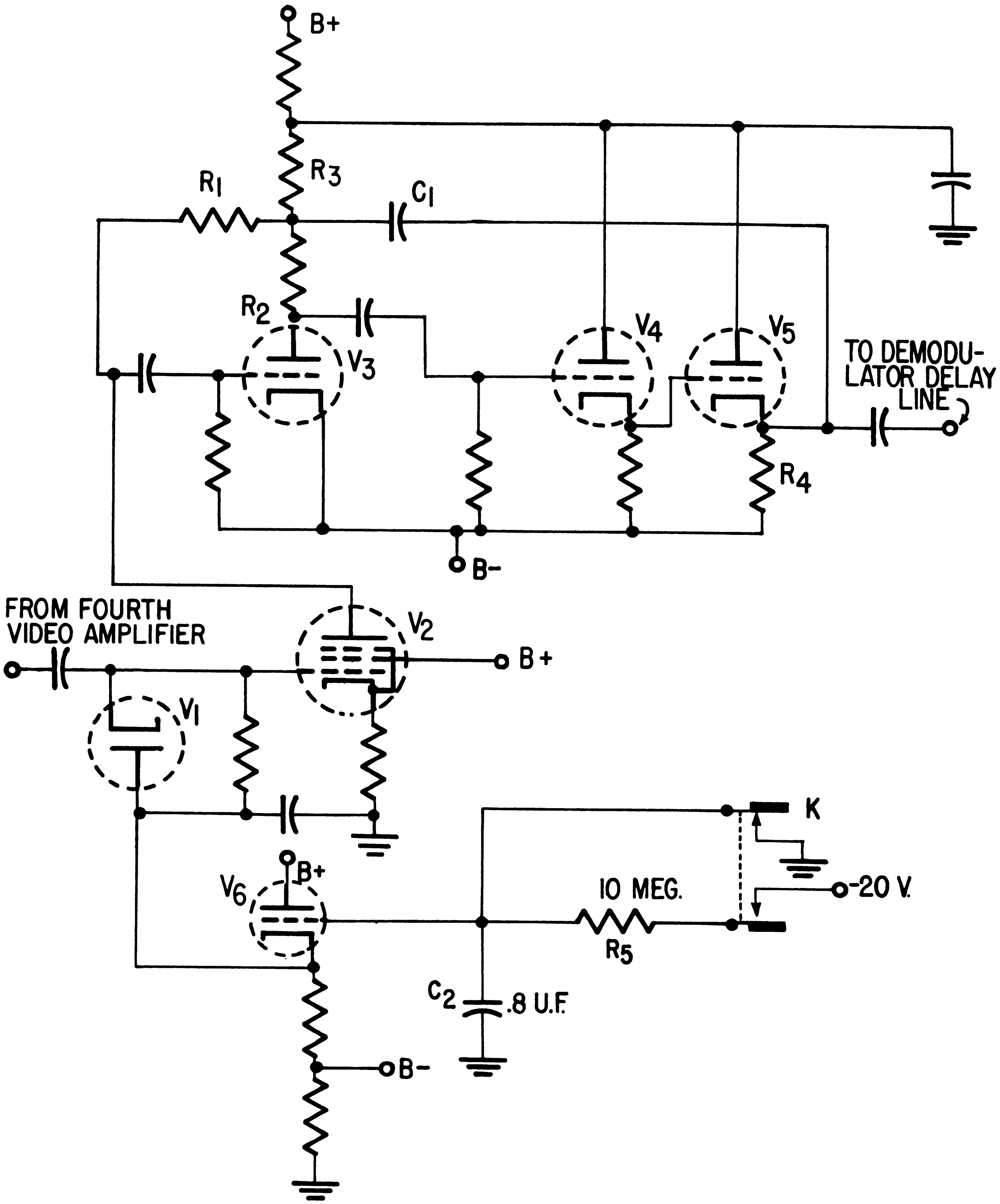


Figure 8-3.—Video and MCV circuits.

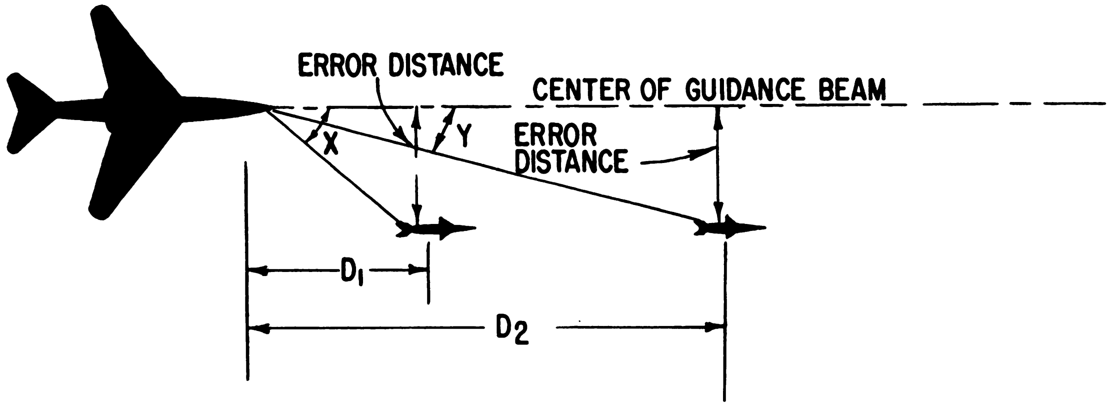


Figure 8-4.—Effect of range on error - signal modulation.

then brings the signal level back to the original value present before the correction was made.

The effects achieved by the MCV and AGC circuits are indicated in figure 8-5. In (A), it is assumed that the missile range is 2,000 feet and the error angle is such that the fly-up signal is three times the fly-down signal, when measured at the output of the video strip. With this signal relationship, the percentage of modulation is 50 percent. At a range twice as great, the signals would be smaller due to increased range and the modulation percentage would be lower due to the smaller angle, as shown in (B). However, the modulation-control circuit causes both signals to be decreased by equal amounts (represented to the left of the line M-M), with the result (C) that the power level is further decreased, but the modulation is increased to the original value of 50 percent.

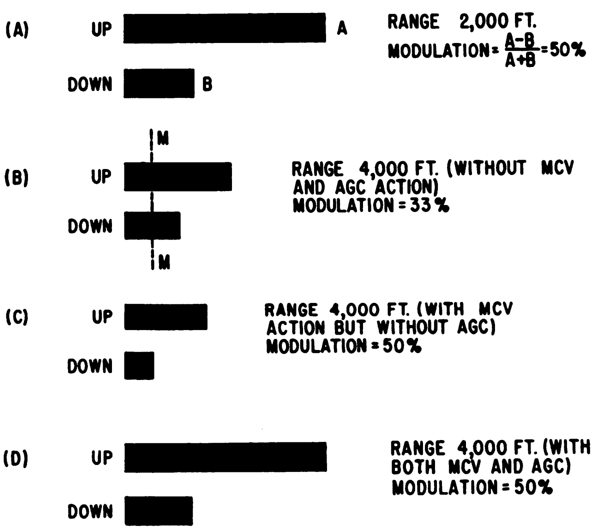


Figure 8-5.—Effect of MCV and AGC on video amplifier output.

The AGC circuits of the first three video amplifier stages then increase the average power level to the original level present at 2,000 feet, as shown in (D) of figure 8-5. The result is a constant output for a constant error distance as the range increases.

The MCV circuit illustrated in figure 8-3 consists of R_5, C_2 the cathode follower (V_6), and the contacts of relay K. The relay, shown in the normal (or deenergized) condition, is energized when the missile switches from automatic-pilot to beam-rider operation. During the former flight phase, the MCV output is maintained at zero volts by the upper relay contacts, which are closed and hence ground the grid of V_6.

When the missile switches to beam-rider operation, the lower relay contacts close and connect R_5 to the negative 20-volt supply, causing capacitor C_2 to begin charging exponentially to the minus 20-volt level. The capacitor voltage is applied to the cathode follower, which in turn, causes the bias of V_2 to increase exponentially as a function of time. As a result of the increasing bias, the amplitudes of the opposing signals developed by the video amplifier are diminished; and the percentage of modulation is thereby increased as the flight time and range of the missile increases.

The time constant of the R-C combination (fig. 8-3) in the MCV circuit is eight seconds. The diode, V_1, is a conventional clamper, which

maintains the d-c voltage in the grid circuit of V_2 at the value determined by the MCV action.

Test Equipment

The principal items of test equipment for the guidance receiver are a quadrant dual-pulse signal generator (QDPG), an oscilloscope, and a d-c voltmeter.

The QDPG produces test inputs that are similar to the signals applied to the unit in actual operation. These voltages are pulse pairs with width, repetition rate, and spacing the same as those in the output of the parent aircraft radar. The relative amplitudes of the test signals can be varied by the operator to vary the percentage of modulation.

The oscilloscope is used to check the operation of the video amplifiers. The d-c voltmeter is employed to measure the signal-voltage outputs of each channel. The measured values are then compared with standard voltage values given in the authorized checkout procedure.

THE GUIDANCE AMPLIFIER

The principal function of the guidance amplifier unit is conversion of the four d-c input signals into two modulated a-c voltages proportional to the up-down and left-right components of the missile's displacement from the center of beam nutation. The input is derived from the guidance receiver and grouped into sets of opposing signals (up with down and left with right); each resulting double-ended signal is then applied to a separate channel in the amplifier unit.

The signals are filtered to remove the radar-antenna nutation frequency and passed through circuits that compensate for undesirable servo frequencies. The error voltages are then amplified and applied to a balanced modulator to which the output of a reference oscillator is also applied. The modulator in each channel is followed by a buffer amplifier.

Operation

Figure 8-6 is a simplified schematic of the balanced modulator and buffer amplifier of the up-down channel, which is similar in operation to the left-right channel of the unit. The modulator circuit is made up of tubes V_1, V_2, and the associated circuit elements. The buffer-amplifier circuit includes all the elements shown between the secondary of T_1 and the output terminals of the channel.

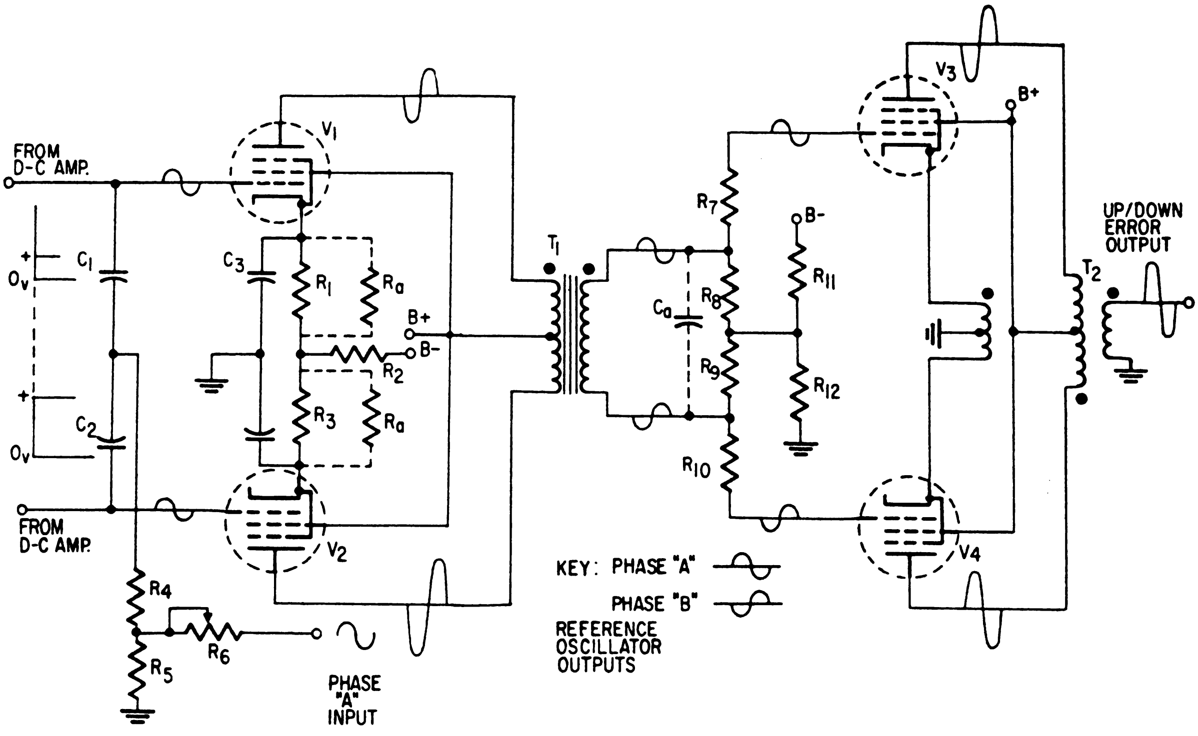


Figure 8-6.—Modulator and buffer amplifier in up-down channel of the guidance amplifier.

The tubes in the balanced modulator have variable-gain characteristics, so that an increase in the positive potential on the control grid of either tube causes a corresponding increase in gain. With zero input, the d-c potentials at the modulator grids are equal and the tubes develop equal output plate potentials. In this balanced condition, the phase-A reference oscillator voltage (fig. 8-6) is completely suppressed in the primary of T_1, and no a-c signal is applied to the buffer amplifier. (The reference oscillator provides carrier voltages for all the control-system signals.)

With the conditions of error voltage illustrated in figure 8-6, the positive d-c potential on the grid of V_2 is greater than the voltage on the grid of V_1. As a result, V_2 has greater gain than V_1 and the signal voltages in the respective plate circuits are as illustrated. The phase relationship of signal voltage in the secondary of T_1 is dependent upon which modulator tube has the greater gain. Thus, if the unequal d-c error voltages at the modulator grids were interchanged, the phase of the output would then be reversed.

The function of the buffer amplifier (containing tubes V_3 and V_4 in figure 8-6) is to match the impedance of the modulator output circuit to the low impedance of the following unit, the component resolver. The matching action is accomplished by degenerative feedback in the cathode circuits of the push-pull amplifier tubes. As in a cathode-follower circuit, the degeneration produces low output impedance.

Test Equipment

The test equipment needed for the circuits illustrated in figure 8-6 includes an oscilloscope, an a-c voltmeter, and a d-c error-voltage simulator. The output of each channel is checked with the voltmeter to insure that the desired gain is maintained for different d-c error inputs. The oscilloscope is used to determine if the output is of the desired phase.

If unbalance is present in the modulator circuit with zero error input, the condition can be corrected by shunting either R_1 or R_3 with a high resistance (indicated by R_a in figure 8-6). This procedure results in a change in the fixed bias of the tube in question and thereby adjusts the gain. To find the correct value of resistance to apply, a resistance decade box is placed first across R_1 and then across R_2 The value of resistance that provides the best balance in the circuit is then inserted. Resistor R_6 is adjusted during channel checkout to set the overall gain of each channel.

In addition to the balance adjustment of the modulator (fig. 8-6), it is also necessary to compensate for phase lags in each channel of the guidance amplifier. These exist between the reference-oscillator input (to the grids of the modulator tubes) and the error output of the channel. The phase lag is introduced by the inductive effects of the transformers and can be corrected by adding the proper amount of capacitance across the output terminals.

With no phase lag present in the channel, the up-down output is either in phase with the reference oscillator voltage (phase A) or displaced from it by 180° (phase B). When the phase relation present differs from these values, a capacitor (C_a) must be placed across the secondary of T_2 Selection of the correct value for C_a is made by attaching the various elements of a capacitance decade box and measuring the resulting phase angles by means of an oscilloscope.

To understand the capacitance adjustment, it is desirable to review the fundamental oscilloscope patterns that indicate phase differences. Those shown in figure 8-7 result when the applied signals are two sine-wave voltages of equal amplitude, one of which is applied directly to the vertical deflection plates and the other to the horizontal plates.

In (A) of figure 8-7, the phase difference of the two voltages is either 0° or 360° and the scope pattern is a straight line tilted at 135 degrees. When the phase angle increases, the line opens into an ellipse (B); and at exactly 90° or 270°, a circle appears. At 180° of phase difference, a straight line is again formed but tilted at 45 degrees. To obtain the circular pattern, it is necessary that the applied signals be of equal amplitude. If the voltages are unequal, the pattern never becomes circular, but is elliptical for angles different from zero or 180°.

The up-down channel phase adjustment is accomplished by applying the phase-A input to one set of deflection plates and the output of the channel to the other set. The capacitance decade box is then attached and adjusted until a straight line appears on the oscilloscope. By selecting an appropriate amount of d-c error input, the amplitudes of the a-c signals applied to the oscilloscope can be equalized.

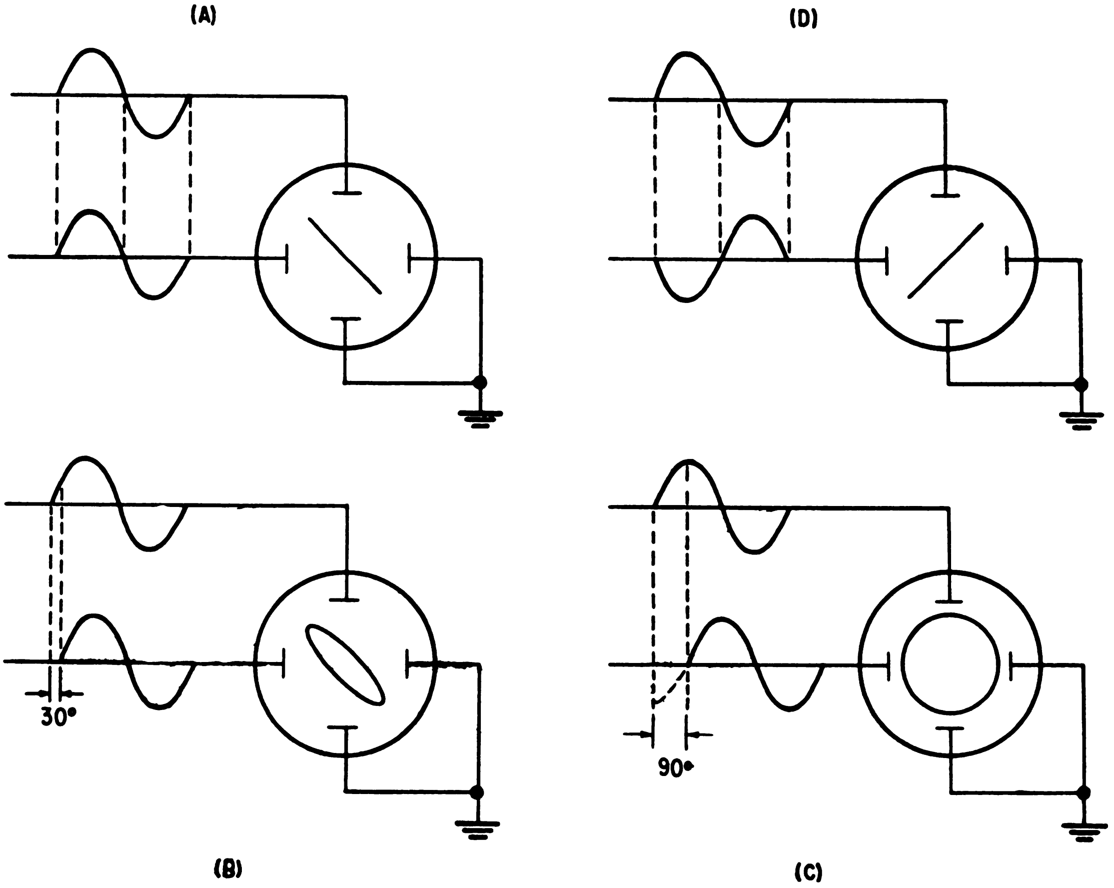


Figure 8-7.—Oscilloscope patterns indicating phase differences.

THE SUMMING AMPLIFIER

The summing amplifier (fig. 8-1) has several functions. It limits the incoming error signal; combines them with stabilizing voltages produced by the pitch and yaw rate gyroscopes; corrects the combined voltages for missile airspeed and altitude; and amplifies the resultants, which are called pitch and yaw commands. The input voltages (pitch and yaw displacement errors), after being referenced to the missile coordinates by the component resolver, are applied to separate channels in the summing amplifier.

The pitch channel is illustrated in figure 8-8 and is similar in circuitry to the yaw channel of the unit. The parallel limiter, consisting of V_1 and associated elements, restricts the maximum amplitude of the pitch signals in order to prevent the wing deflections from becoming large enough to overstress the missile structure. (Limiters of this type are discussed in chapter 4 of this course.) The cathode follower, V_2, isolates the limiter from the summing network to eliminate undesirable loading effects.

The summing network (fig. 8-8) is made up of resistors R_7, R_8, R_9, and R_{18}. (Resistors R_{16} and R_{17} form active parts of the network only during automatic-pilot operation and are grounded during the beam-rider phase.) The function of the summing network is to combine the output signals from the limiter with signals from the pitch rate gyro. The manner of combination is determined by the phase relations of the signals, which are either in phase or 180° out of phase. In the former condition, the guidance and stabilizing signals add in the network; in the latter condition, subtraction of voltages takes place. The resultant signal is than amplified in the variable-gain stage containing V_3 and V_4, the output of which is corrected for missile altitude and velocity by means of a voltage derived from a gain-control pressure gage.

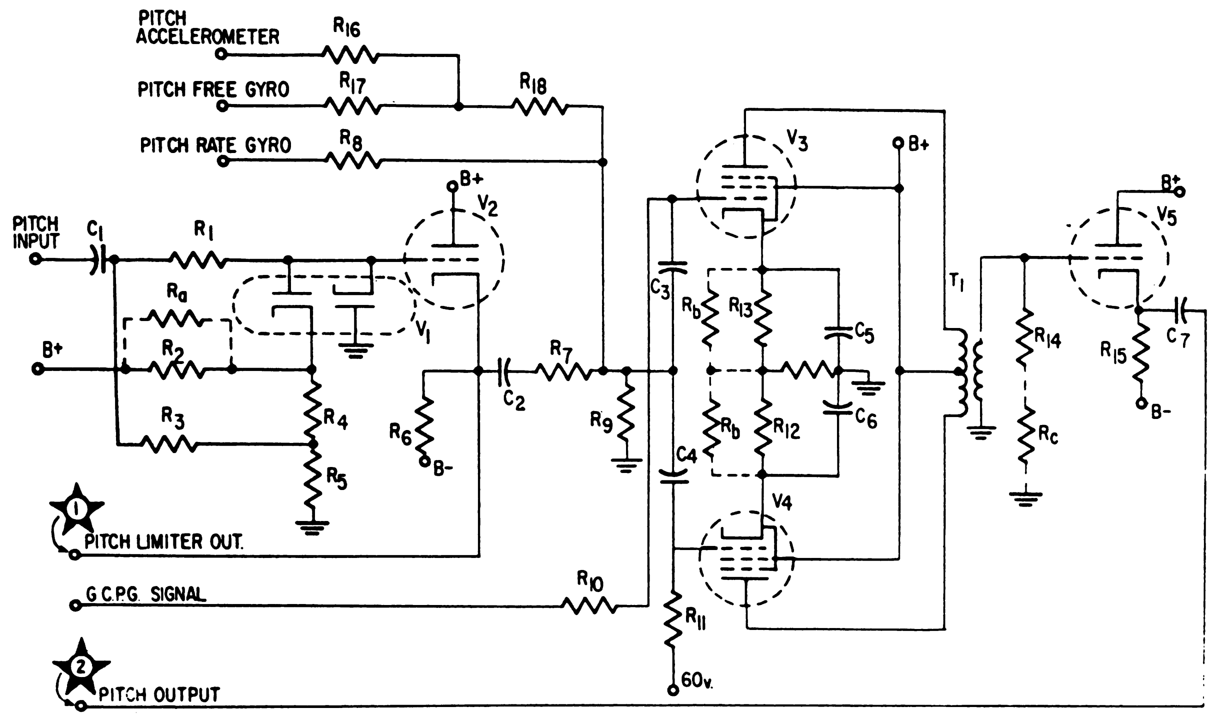


Figure 8-8.—Pitch channel of summing amplifier.

The gain-control pressure gage (GCPG), an instrument sensitive to airspeed and air density, is located in the nose of the missile. It produces a d-c voltage that varies directly with the missile altitude and inversely with the velocity. This voltage controls the amplification of the variable-gain stage (V_3 and V_4 in figure 8-8) and hence, corrects the output for the two conditions mentioned.

The two pentodes, V_3 and V_4, are fed push-push in the grid circuit, while the plates are connected so that signal subtraction occurs at the output, thus operating as a differential amplifier. A circuit of this type is required in this application because of the wide range of altitude in which the missile operates. The cathode follower associated with the pentode stage is an impedance matching device for coupling the high impedance of the amplifier output with the low impedance of the following stage.

The graph (fig. 8-9) indicates the variable-gain characteristics of the differential amplifier under control of the GCPG. With tube V_3 only in the circuit, the gain varies from about one to five. With V_4 in the circuit and operating with a fixed, d-c grid voltage, the output is lower because of the subtracting action of the two tubes. In this condition, the gain changes over a range from 1/4 to 3 (or in a ratio of 1 to 12). The signal loss due to V_4 is made up by the increase in voltage provided by the step-up transformer, T_1.

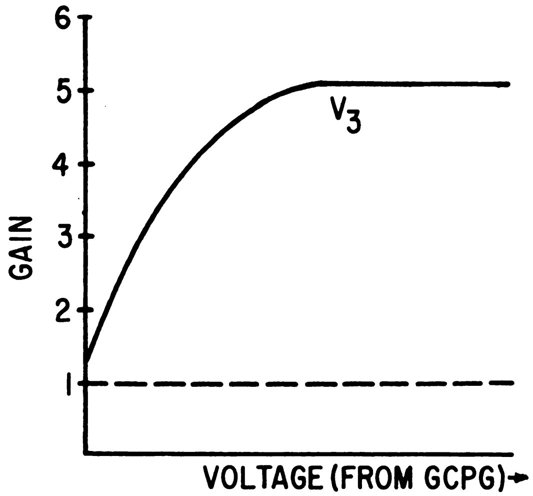


Figure 8-9.—Amplifier gain characteristics.

The test equipment required for checkout and adjustment of the summing amplifier and also the procedures employed are discussed in detail in the last two sections of this chapter.

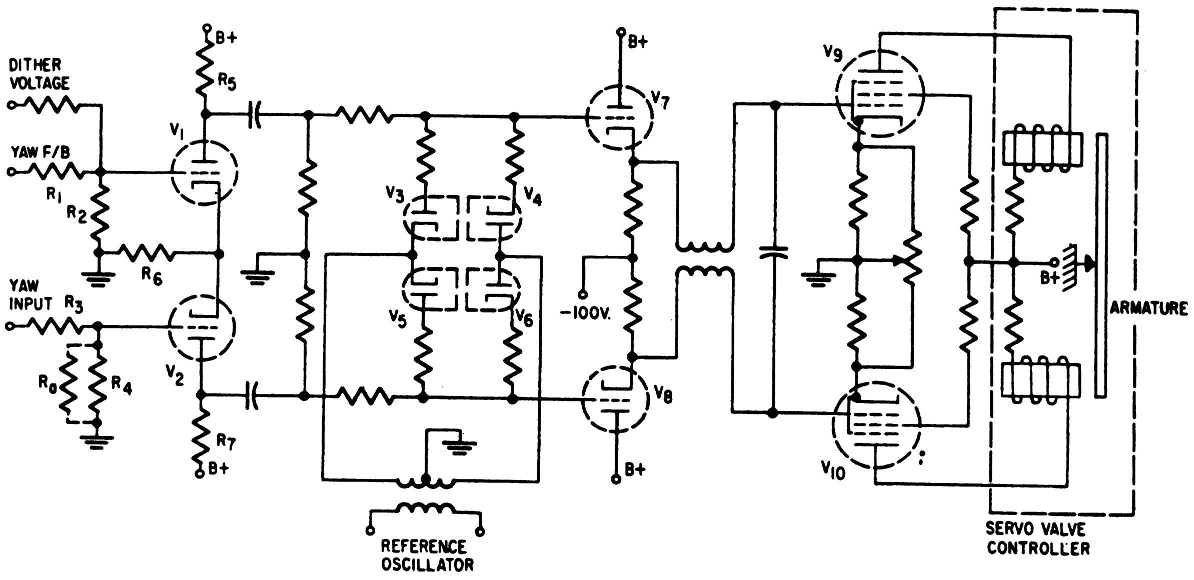


Figure 8-10.—Yaw channel of the servo-amplifier unit.

THE SERVO AMPLIFIER

The last electronic component of the beam-rider control system, the servo amplifier, converts a-c command signals into mechanical motions of the wing-actuator valves. The unit contains two channels for separate control of pitch and yaw actuators. Each channel is composed of four stages: a phase inverter, a phase-sensitive demodulator, a push-pull cathode follower, and a push-pull, d-c power amplifier.

The Phase Inverter

The yaw-channel circuits are illustrated in figure 8-10. The phase inverter (V_1 and V_2) receives single-ended, a-c signals from the summing amplifier and converts them into double-ended, push-pull outputs for application to the demodulator. It also sums the command voltages with a-c feedback voltage derived from the wing potentiometer, and combines the resultant with the output of a "dither" oscillator.

The fundamental action of the phase inverter is illustrated by the simplified schematic in figure 8-11. The important element in the operation of the circuit is the common cathode resistor, R_6, through which the plate currents of both tubes flow. Assume that a signal is applied to the grid of V_1 and that no signal is present at the input of V_2. The value of the

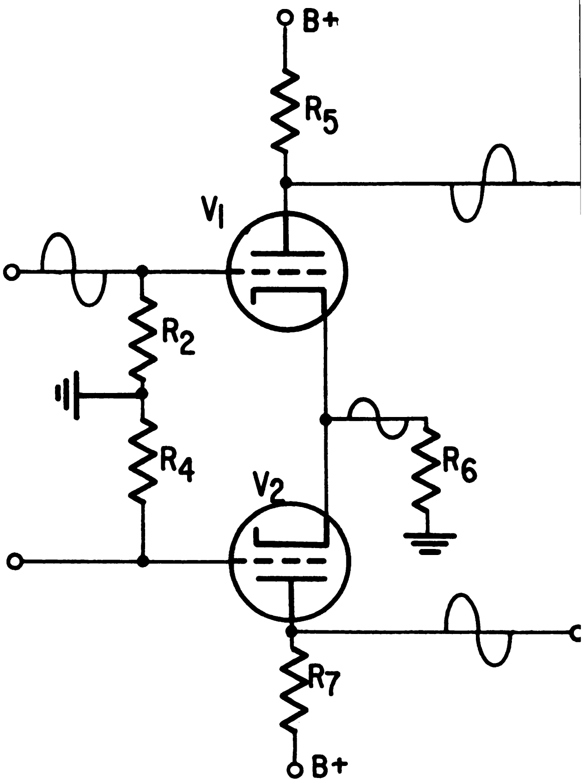


Figure 8-11.—Phase inverter action.

cathode resistor is chosen so that it develops a voltage about one-half that applied to the grid of V_1. This means that the effective signal between grid and cathode of the tube is only half the value of the voltage applied between grid and ground.

When no signal is applied to the grid of V_2, it functions as a grounded-grid amplifier; and in the condition shown in figure 8-11, the effective signal (between grid and cathode) is of the same magnitude but of opposite phase to the signal of V_1. The two tubes have the same gain; hence the signals produced in the two plate circuits are 180° out of phase and of the same amplitude.

Demodulation and Amplification

The operation of phase-sensitive demodulator circuits and power amplifiers of the type shown in figure 8-10 is discussed in chapter 8, *GF 3 & 2*. To fulfill the purposes of this chapter, it is sufficient to point out the principal functions performed. The demodulator (V_3 through V_6) is essentially a keyed bridge rectifier, which is alternately switched into and out of conduction by the reference-oscillator voltage. It compares the phase of the a-c signals with that of the reference voltage, rectifies the a-c command signals, and develops two sets of half-wave pulses, the relative polarity of which depends upon the phase relation of the signal and reference voltages.

The half-wave pulses are applied to the cathode-follower tubes (V_7 and V_8 in figure 8-10), which drive the grids of the push-pull power tubes (V_9 and V_{10}). The plate currents of the final tubes vary in relative amplitude in accordance with the applied grid voltages, thereby operating the two solenoids, which position an armature. This element controls the valves of the hydraulic wing-actuator in the missile hub section, which in turn, controls the yaw wings. A similar sequence of actions occurs in the pitch channel to control the pitch wings.

Dither Voltage

Among the voltages checked during testing of the servo amplifier is the dither-oscillator output, which is combined with the error information in the phase inverter. The purpose of the dither voltage is to minimize the effects of static friction in the hub section. In frequency, it is about one-tenth that of the reference voltage and hence passes through the demodulator without appreciable change and appears in the output of the d-c power amplifier. The result is a low-frequency flutter of the wing-actuator units and consequent removal of frictional effects in the response of the servo system.

Test Equipment

The test equipment used to check and adjust the servo amplifier includes a filament supply, an Amplifier Test Set, a frequency meter, a vacuum-tube voltmeter (VTVM), and an oscilloscope.

The filament supply provides filament power for both the Test Set and the servo-amplifier unit. B-plus and other operating voltages are supplied by the Test Set. The latter also contains a reference oscillator, a series of decade resistance banks, a capacitance bank, and a vacuum-tube voltmeter.

The oscillator in the tester produces an output that is controllable in phase and amplitude for use as the reference voltage (applied to the phase-sensitive demodulator) and for making amplifier gain tests. The decade resistance banks and also the capacitance bank are employed in adjusting the dither oscillator, which is located in the servo-amplifier package. The voltmeter in the test set is used as an indicator when null and balance tests are made on the unit.

The frequency meter is employed to check the frequency of the dither oscillator. The output of this oscillator is checked by the VTVM, which also serves as an aid in troubleshooting faulty units. The oscilloscope is required for tests made on the phase-sensitive demodulator for proper half-wave rectification.

Typical Electronic Component Test Equipment

Typical test setups for checkout of missile electronic components include specialized test sets, both low- and high-voltage power supplies, and standard instruments such as oscilloscopes and vacuum-tube voltmeters. There are many similarities in the test equipment and also in the procedures of component testing; hence it is not necessary to describe in detail the setup for each of the components discussed in this chapter. Rather, a single example is given to point out the characteristic features of the equipment

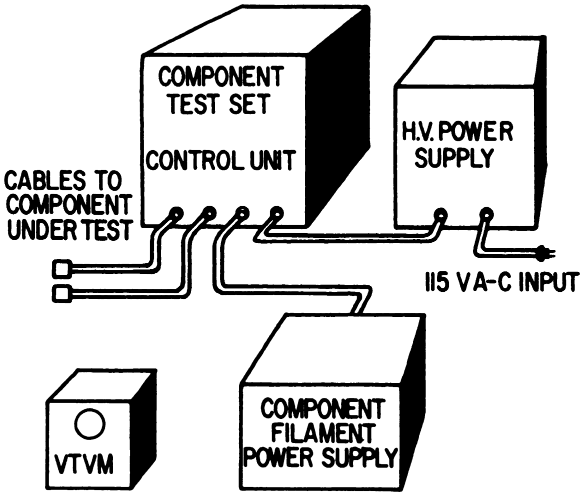


Figure 8-12.—Summing amplifier test setup.

and test methods employed in component checks.

The setup used for checking the summing amplifier is shown in figure 8-12. The major units include an Amplifier Test Set, a filament supply, a B-plus supply, a vacuum-tube voltmeter, and the necessary cables for connecting the summing amplifier and the test equipment.

The following facilities are supplied by the test setup:

1. Signal voltages, controlled in amplitude and phase, which simulate the signal information fed to the summing amplifier during operation in the missile.
2. Switching circuits for selecting various parts of the unit for special tests and for returning the output data to the test set for indication and evaluation.
3. D-c supply voltages which correspond to those normally fed the unit while in the missile and which render it operative for test purposes.
4. Resistance and capacitance decade boxes for making the required adjustments of certain circuits in the component.

SIGNAL SIMULATING CIRCUITS

The signal generator and control circuits of the Amplifier Test Set are shown schematically in figure 8-13. The test signals are developed by a phase-shift oscillator of the type discussed in chapter 11, *GF 3 & 2*. The oscillator consists of the left-hand section of V_1 and associated circuit elements. The other half of the tube is connected as a cathode follower, the purpose of which is to prevent excessive loading of the oscillator.

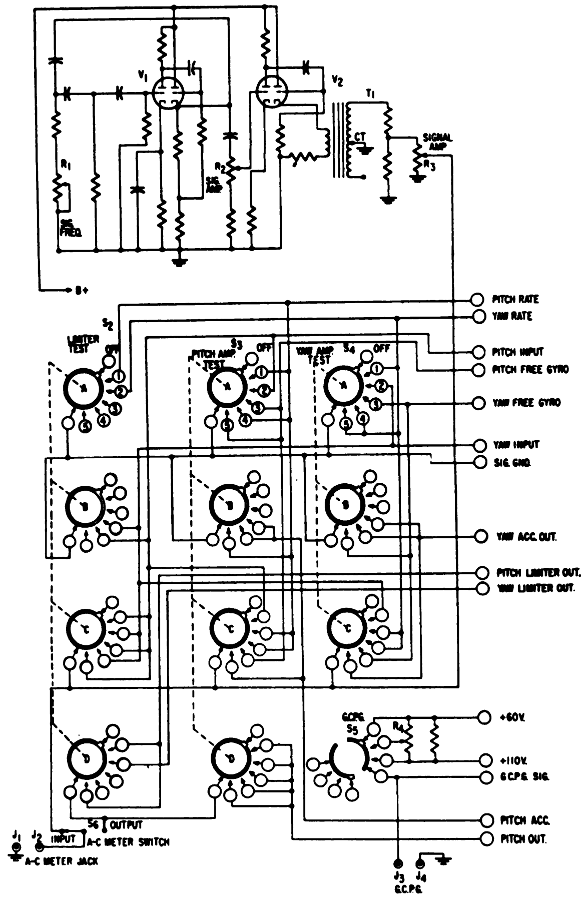


Figure 8-13.—Summing Amplifier Test Set.

The twin-triode, V_2, is a combination amplifier and cathode follower. The signal voltage is applied to the amplifier grid; the output, taken from the cathode, is coupled to the switching circuits through a transformer, T_1. The potentiometer, R_2, in the amplifier grid circuit serves as a control device for adjusting the voltage level of the signals applied to the transformer primary and is set in accordance with specifications in the missile handbook.

SWITCHING CIRCUITS AND DECADE RESISTORS

The principal controls of the Test Set consist of the switches and potentiometers shown in figure 8-13. These controls permit the operator to select individual circuits in the summing unit for specific checkout and to adjust the amplitude of applied test voltages.

The signal amplitude control, R_3, regulates the voltage applied to the limiters and

amplifiers of the component under test. The limiter test selector switch provides the means for feeding test signals to each limiter in turn, while the output of each is evaluated by indications of the VTVM, which is connected at the A-C Meter jacks, J_1 and J_2.

The Pitch Amplifier Test Selector Switch, which has six positions and four decks, feeds the required signal to the pitch amplifier of the summing unit. The a-c output of this stage is then read off at the panel of the tester by the VTVM. The Yaw Amplifier Test Selector Switch performs a similar function for the yaw channel.

The GCPG Selector Switch, S_5, is a single-deck, three-position, rotary switch used to set the bias on the variable-gain amplifiers of each channel. The voltage it applies simulates the gain-control pressure gage output present in actual operation of the missile. In the GCPG check, a d-c VTVM is connected to J_3 and J_4; and the potentiometer R_4 is adjusted for a reading of positive 64 volts with the switch in position 2.

The A-C Meter Switch (S_6 in figure 8-13) is a double-throw toggle switch that selects either the input or output signal voltage applied to the meter jacks, J_1 and J_2. The VTVM, when connected to these jacks, serves as the indicating device for evaluation of both input and output signal voltages.

An example of the resistance decades contained in the Test Set is shown in figure 8-14. The device consists of precision resistors and the necessary switching circuits and permits substitution of known values of resistance in the summing amplifier stages during operation. The purpose of the substitution is to find the correct value of resistance to add to a particular limiter or to a push-pull amplifier to compensate for changes in the circuit elements or in the tube parameters.

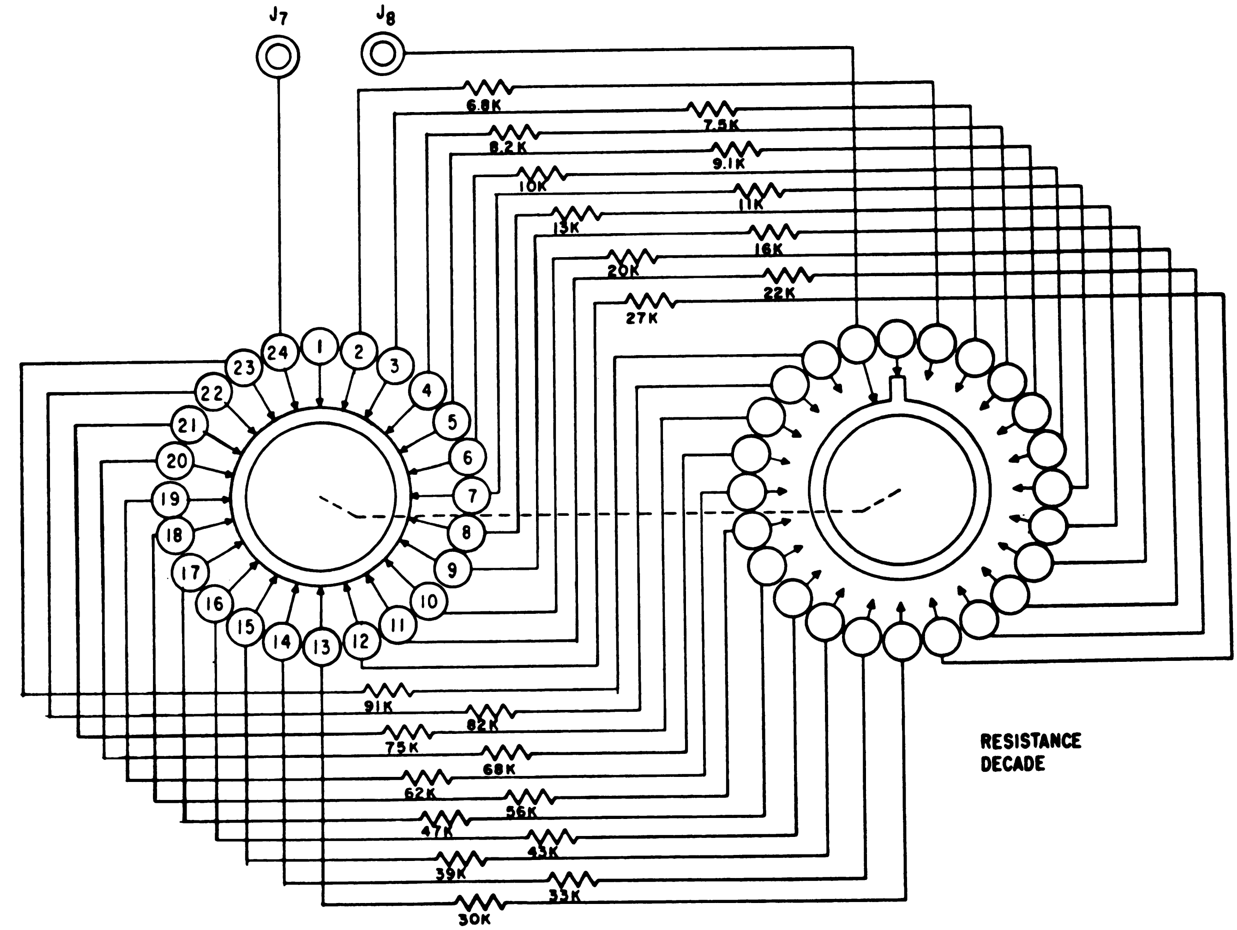


Figure 8-14.—Resistance decade in Amplifier Test Set.

Summing Amplifier Checkout Procedures

The authorized checkout procedure for the summing amplifier is based on the setup illustrated in figure 8-12. The component under test is connected as indicated, operating power is applied, and the equipment is allowed to warm up for three minutes before checkout is begun.

The procedure then employed can be illustrated by table 8-1, which lists some of the specific checks for the pitch-channel stages (fig. 8-8). This information is presented in the form used in the *Handbook of Assembly, Checkout, and Service Instructions* of the missile under consideration. The table shows the operational steps in the order in which they are performed and the major check points in the component at which test outputs are taken. Check points are also shown in the summing-amplifier schematic by numbers enclosed in starred circles.

To understand the various steps of the checkout procedure, it is necessary to refer to the diagram of the Test-Set switching circuits (fig. 8-13), which contain the controls referred to in table 8-1. At each step, the controls are set to the positions given in the table under "Test Equipment Control Positions" so as to route the output voltage at the corresponding check point to the A-C Meter jacks. A vacuum-tube voltmeter connected to the jacks gives the output reading at each test step, and these indications are then compared with the values in the column labeled "Normal Indications" to evaluate the performance of the component.

From the information derived in the checkout procedure, the operator must determine whether the package under test requires adjustment. If so, he follows the directions given in table 8-1 under the heading "Possible Cause of Abnormal Indication." Consider for example, the three possible adjustments indicated in figure 8-8. Resistor R_a is added in parallel with the existing resistor to adjust the proper level of signal output in the limiter of the pitch channel; R_b is used to make balance adjustments on the variable-gain amplifier stage; and R_c is used to make the output gain adjustment for the channel. These adjustments are made by utilizing the resistance decades in the Test Set (fig. 8-14) according to detailed instructions accompanying the checkout procedure given in the handbook.

Table 8-1.—Checkout procedure for summing amplifier.

Step	Test Point	Test Equipment Control Positions	Normal Indications	Possible Cause Of Abnormal Ind.
1	1	Place the GCPG switch on Pos. 2. Connect the a-c VTVM to the a-c meter jacks. Place the Limiter Test switch to Pos. 5. Adjust the Signal Amp. Control for 16 volts on VTVM. Put A-C Meter switch to Output position. Read VTVM.	VTVM reads 4.2 to 5.1 volts.	Pitch channel circuit out of adjustment.
2	2	Place the Limiter Test switch to OFF position. Place Pitch Amp. Test switch to position 1. Place the A-C Meter switch to Input Position. Adjust the Signal Amp. Control for 2.75 v. indication on VTVM. Place the A-C Meter switch to Output position. Read VTVM.	VTVM indicates 2.4 to 3.2 volts.	Pitch variable gain amplifiers or output circuit.
3	2	Place GCPG switch in position 3. Read VTVM.	VTVM should indicate 15.0 to 20.0 volts.	Pitch variable gain amplifiers at maximum gain.
4	2	Place GCPG switch on position 2. Place Pitch Amp. Test switch on position 2. Place A-C Meter switch on the Input position. Adjust Signal Amp. Control for a 1.0-volt reading on the VTVM. Place the A-C Meter switch on the Output position. Read VTVM.	VTVM should indicate 1.2 to 1.6 volts.	Summing resistors R_8 or R_9. Variable gain amplifiers or output circuit.

Table 8-1.—Continued.

Step	Test Point	Test Equipment Control Positions	Normal Indications	Possible Cause Of Abnormal Ind.
5	2	Place the Pitch Amp. Test switch to position 4. Place A-C Meter switch on the Input position. Adjust the Signal Amp. Control for 1.0-volt indication on the VTVM. Place the A-C Meter switch on the Output position. Read VTVM.	VTVM indicates 2.8 to 3.8 volts.	Summing network resistors.

QUIZ

1. The two principal classes of missile checks are
   a. GO, NO-GO and component
   b. systems and component
   c. GO, NO-GO and systems
   d. operational and bench test

2. A beam-rider missile derives its guidance intelligence from
   a. the target
   b. the parent aircraft
   c. spin modulation
   d. Doppler shift

3. What characteristic of the pair-pulse output of the QDPG is varied to check the MCV circuitry?
   a. Phase
   b. Reference
   c. Frequency
   d. Amplitude

4. The input to the guidance receiver consists of
   a. a-c signals variable in amplitude
   b. d-c signals variable in phase
   c. a-c signals variable in phase
   d. d-c signals variable in amplitude

5. A fly-up signal is characterized by
   a. pulse amplitude
   b. pulse spacing
   c. pulse repetition
   d. pulse-pair frequency

6. The preamplifier of the tail section serves as a/an
   a. impedance matching device
   b. tuned circuit
   c. high-Q multiplier
   d. band-reject filter

7. Dither is applied to
   a. increase servo amplifier response
   b. overcome static friction of power amplifiers
   c. serve as a reference for phase inversion
   d. decrease mechanical lag in the hub section

8. The principal function of the tail section is to receive,
   a. detect, and filter
   b. demodulate, and modulate
   c. detect, and amplify
   d. detect, and rectify

9. Tunable TR tubes are adjusted by using a
   a. frequency counter
   b. GO, NO-GO tester
   c. spectrum analyzer
   d. a-c voltmeter

10. In figure 8-3, tube V_1 is a
    a. rectifier
    b. clamper
    c. detector
    d. regulator

11. The guidance amplifier input filter is used to remove the
    a. dual pulses
    b. servo frequencies
    c. nutation frequency
    d. reference signal

12. In testing the circuit shown in figure 8-6, an oscilloscope is used to check signal
    a. phase
    b. amplitude
    c. frequency
    d. gain

13. What phase and amplitude relationships of two signals produce a circle on an oscilloscope?
    a. 180 degrees apart and equal
    b. 90 degrees apart and unequal
    c. 135 degrees apart and equal
    d. 270 degrees apart and equal

14. One of the functions of the summing amplifier is to
    a. provide a d-c output
    b. reference the signal to missile coordinates
    c. isolate the component resolver from the servo amplifier
    d. limit the incoming signal

15. The gain-control pressure gage is sensitive to
    a. speed and altitude
    b. variable-gain tubes
    c. summing amplifier inputs
    d. target speed and altitude

16. In figure 8-8, the cathode resistor of V_1 provides
    a. input signal stabilization
    b. positive voltage at the grid of V_2
    c. grid resistance for V_2
    d. mixing voltage for V_1

17. In figure 8-3, the amplifier tube V_3 is stabilized by
    a. regenerative feedback applied through C_1
    b. regenerative feedback applied through R_1
    c. degenerative feedback applied to the grid through R_1
    d. degenerative feedback applied through the grid resistor

CHAPTER 9
TESTING ELECTRONIC POWER SUPPLIES

When testing electronic power supplies, the missileman employs both theoretical and practical knowledge of many kinds. He must have a good working knowledge, not only of electronic rectifiers and regulators, but must also understand the functions of many related items such as batteries, vibrators, transformers, filters, and the basic electrical machines. It is necessary that he understand the operation and capabilities of specialized and general-purpose test equipment; and he must be familiar with the authorized procedures for testing the particular units involved.

It is to this general area of the missileman's qualifications that the present chapter is related. The first section gives examples of typical supplies; the second is concerned with a representative test set; while the third is a discussion of test procedures illustrated by means of the electronic units described in the first and second sections. The material of the chapter is specialized in nature, and it is necessary that the trainee go to the basic texts for information on the principles underlying the equipment described. Chapter 3, *Basic Electronics*, NavPers 10087, is the principal source on basic rectifier circuits, filters, regulators, voltage doublers, and power machinery such as dynamotors and inverters. *GF 3 & 2,* NavPers 10379, gives the necessary information concerning basic missile power equipment, including batteries, inductor alternators, and prime movers for generators.

Typical Power Supplies

The function of rectifier units and other d-c supplies in missile systems is to provide the high-potential outputs needed for operating the electronic equipment of the guidance and control systems. The input applied to the rectifiers is derived from the primary electrical source carried in the missile. This source is either a battery pack or else an a-c generator, or alternator, driven by a prime mover such as a gas turbine or a fluid motor.

In some d-c systems, input for the rectifiers is produced by means of vibrator-transformer combinations; in others, the low-voltage direct potential is converted by means of rotating machines. In a-c systems, the primary source voltage is usually applied directly from the alternator to power transformers, which, in turn, step up the voltage for subsequent rectification, filtering, and regulation. The following section gives examples of electronic power supplies in both d-c and a-c systems.

SYSTEMS CONTAINING ROTATING MACHINES

The system illustrated in figure 9-1 is representative of missiles employing rotating equipment powered from a battery source. An inverter and a dynamotor supply the required voltages, both a-c and d-c. Both are driven by the 25-volt output of a battery pack containing single-discharge, silver-zinc battery cells (of the type described in *GF 3 & 2,* pages 309-310). The electronic section of the system includes a voltage-doubler circuit, filter networks, and VR-tube regulators. In some instances, inverters and dynamotors are housed in single assemblies; in the case illustrated, however, the machines are separately mounted and the inverter speed is about twice that of the dynamotor.

The Inverter

Two a-c voltages are generated by the four-pole inverter (fig. 9-1). One is a single-phase output of about 150 volts; the other, a two-phase voltage, is a comparatively low potential and is attached to the terminals of J_1 for distribution to various units in the missile. The battery pack supplies excitation voltage both for the motor and the generator sections. The output of the generator remains almost constant under varying load but varies directly

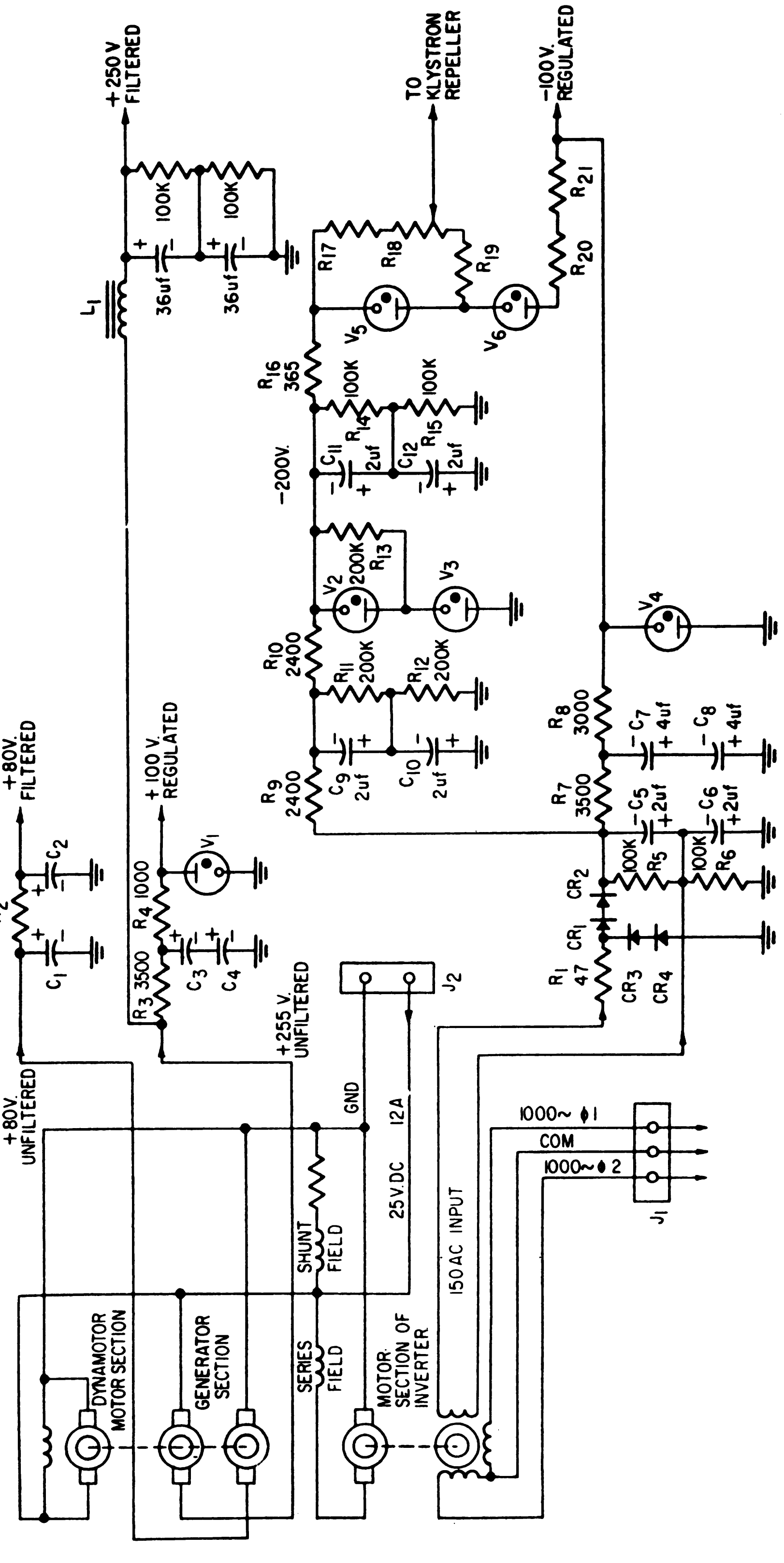


Figure 9-1.—Electrical system with rotating equipment.

with changes in the applied d-c voltage. Since the terminal voltage of the battery pack changes very little under load conditions, the amplitude of the generated a-c outputs is sufficiently constant that no adjustments are required.

The Dynamotor

As in the inverter, the motor of the dynamotor is excited directly by battery voltage, thereby driving a shaft containing two generator armature windings. Unlike those of the inverter, these armature windings are attached to commutators and hence produce pulsating d-c outputs. One, at approximately 80 volts, is applied to an R-C filter composed of C_1, C_2, and R_2 and emerges as unregulated but well-filtered direct current. The other output, 255 volts, is applied both to an L-C-R filter and to an R-C network with a voltage regulating tube, thereby producing two d-c potentials, an unregulated 250 and a regulated 100 volts.

Negative Voltage Supplies

The 150-volt, a-c output of the inverter (fig. 9-1) is applied to a voltage-doubler circuit composed of four dry-disk rectifiers (CR_1 through CR_4) and an R-C filter. Resistor R_1 serves as a current limiting device to protect the rectifiers from surges. Two regulated outputs are derived from the tap at the junction of C_5 and R_7 which is at a potential of approximately 280 volts, negative. Reduced to a negative 100 volts by resistors R_7 and R_8, the resulting voltage is maintained at a constant level by V_4, a gaseous regulator tube.

The other negative voltage developed from the 280-volt tap is applied to the repeller plate of a klystron local oscillator. It is first reduced to negative 200 volts and regulated at this value by tubes V_2 and V_3. Further regulation at a lower value is provided by V_6; while tube V_5 is a protective device used to maintain the klystron repeller voltage within safe limits during extreme changes in the power-supply load.

ELECTRONIC RECTIFIERS

The rectifier shown in figure 9-2 is an example of an all-electronic power device packaged as a plug-in component, which can be removed and tested as a separate entity. Functionally, the rectifier transforms an a-c applied voltage into seven d-c outputs, three of which are stabilized by electronic regulator circuits. Physically, the constructional features are compactness and accessibility of inner parts.

The rectifier (fig. 9-2) is constructed on a base casting of irregular shape which serves as the main supporting structure. The parts are enclosed by two metal covers that can be removed easily to allow access for removal of tubes or adjustment of any of several variable resistors. Removal of the front cover exposes the rectifier tubes, the entire regulator assembly, and the power transformer. Removal of the aft cover reveals the filter capacitors and the voltage-adjusting resistors. The filter chokes are mounted on the base and can be reached when both covers are removed. All electrical connections to the missile circuits are made by cables which attach to multipin connectors situated behind access holes in the sides of the covers.

Circuit Analysis

The overall operation of the rectifier unit can be understood by study of the schematic diagram in figure 9-3. Six double-diode tubes (V_{10} through V_{15}) are connected to transformer T_1 as full-wave rectifiers. Four of the diodes are operated in parallel pairs (V_{11} with V_{13} and V_{12} with V_{14}) to give the required current-carrying capacity. Each of the d-c output circuits contains a capacitor-input, pi-section filter, with chokes L_1 through L_4 acting as the inductive branches of the filter networks. Tubes V_1 through V_9 are employed in the three voltage-regulator circuits, which produce positive output potentials of 32, 170, and 350 volts. The remaining four output voltages of the unit are unregulated.

The electronic regulator circuits operate on the general principle discussed in *Basic Electronics*, pages 130-135, and illustrated in figures 3-19 and 3-20 of the same text. Consider first the application of this principle in the 32-volt regulator, which contains tubes V_8 and V_9 (fig. 9-3). The former tube, a gaseous regulator of the VR type, maintains a constant reference potential on pin 2, one of the grids of the twin triode, V_9. The two triodes operate in series, thereby distributing the fairly large voltage drop resulting from reducing the input to the 32-volt level.

The constant voltage across V_8 is divided by the series resistors, R_3, R_4, and R_5; and

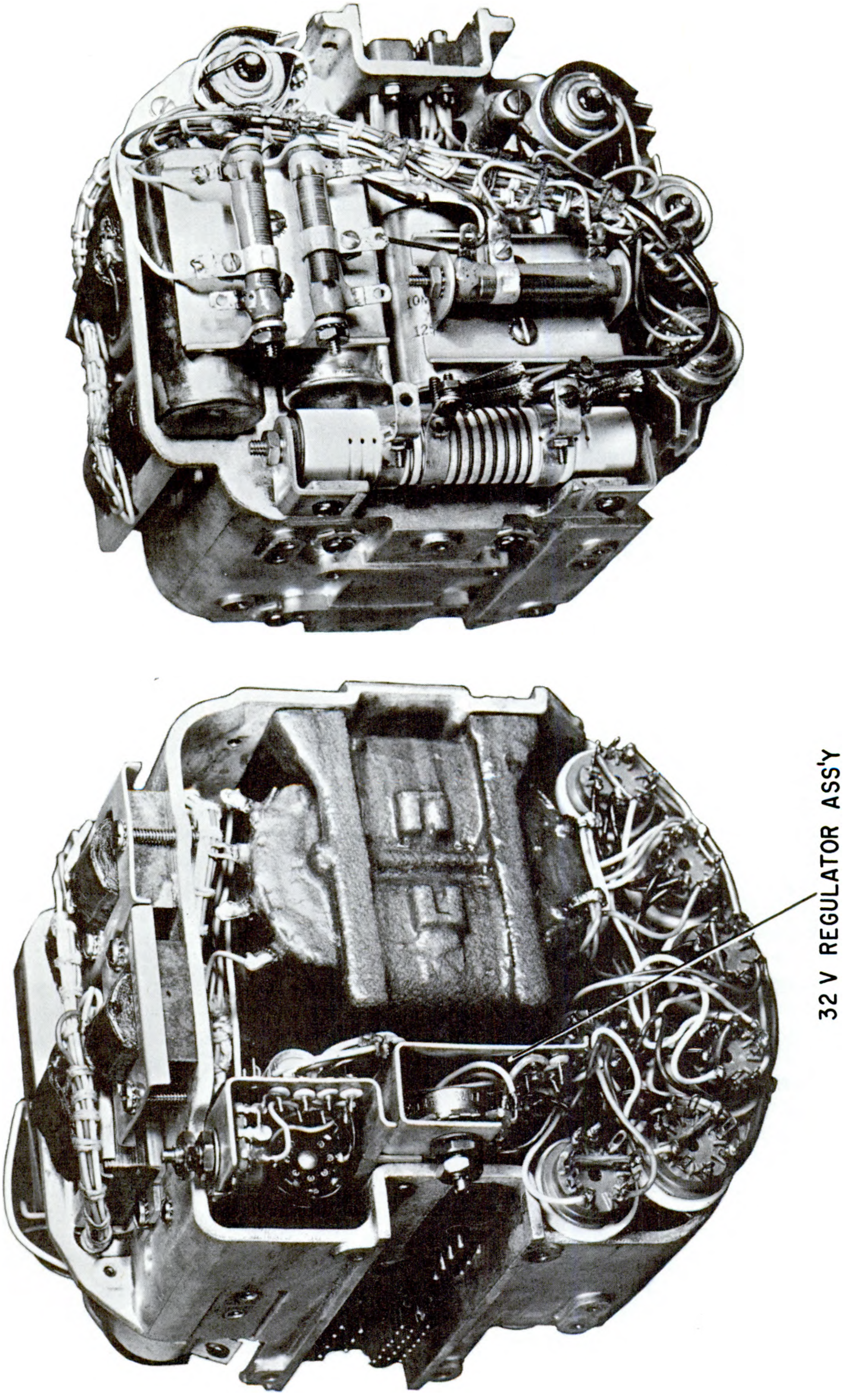


Figure 9-2.—Packaged rectifier unit.

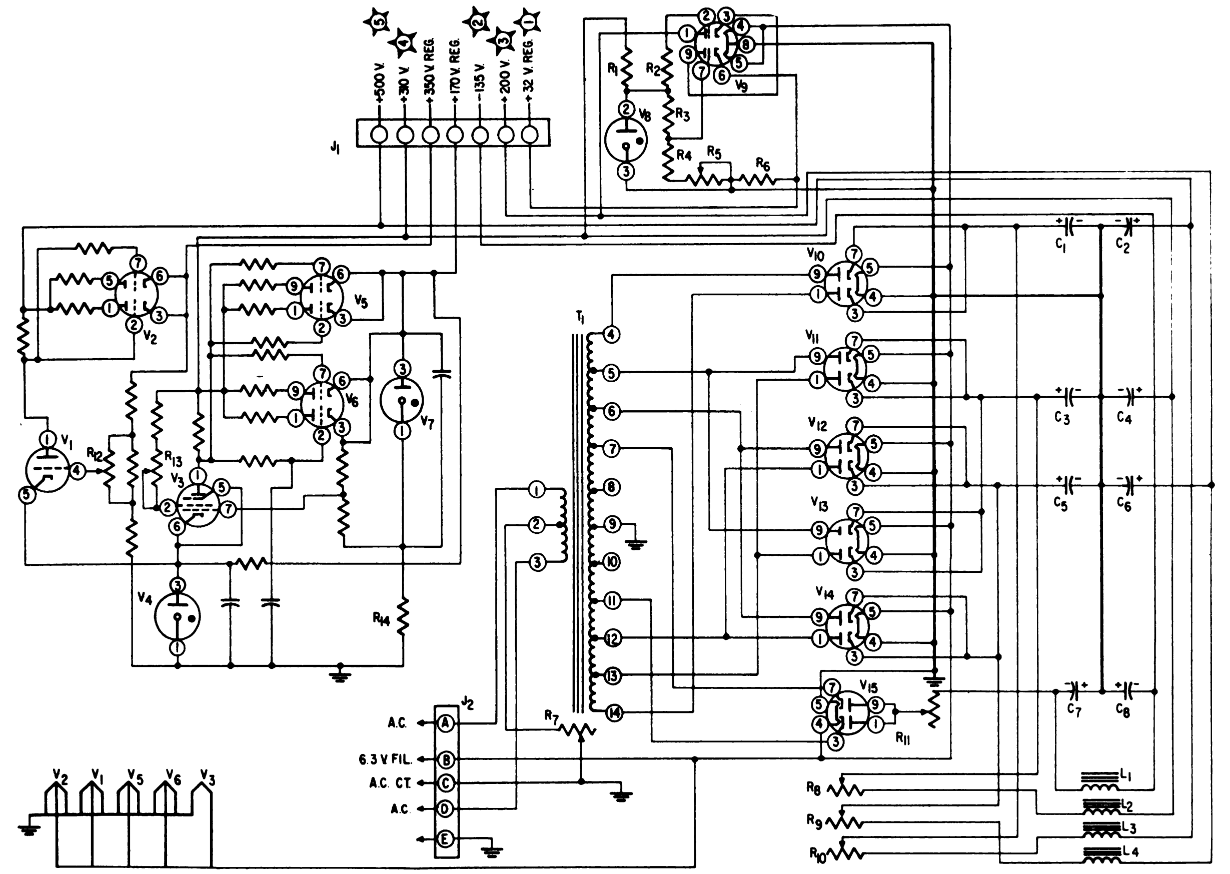


Figure 9-3.—Schematic diagram of rectifier unit.

the latter, a potentiometer, applies a fraction of this voltage to one of the grids of V_9 to serve as a bias potential. The value of this bias determines the normal level of the output.

The action of the regulator is such that any change in the output results in a corresponding change in the voltage across V_9 with the result that the output is held at the desired 32-volt value. Thus, if the output voltage at pin 6 increases, it is reflected as an increase in the bias of the associated grid. This causes an increased voltage drop across V_9 which lowers the output to the original value. Following negative swings of the output, the cathode of V_9 becomes less positive, the bias decreases, the series voltage drop falls off in value, and the output potential then rises. Changes in the applied input potential also cause changes in the output voltage which result in readjustment of the drop across V_9; thus, the circuit compensates indirectly for input fluctuations as well as for variations at the output terminals.

The 170-volt regulator can be identified in figure 9-3 by the triodes, V_5 and V_6, and by the pentode control tube, V_3. The triodes, which are connected in parallel to provide adequate current-carrying capacity, serve the same purpose as V_9 in the 32-volt regulator. The pentode has two functions. It operates as a high-gain, d-c amplifier for output-voltage variations, and it enables the regulator to respond directly to changes in the input voltage. Because of the latter action, the effects of any ripple present in the 310-volt supply are practically eliminated. This is accomplished by use of the screen grid of V_3 which is supplied by the 310-volt lead. The screen is operated without a bypass capacitor so that it follows variations in the applied voltage; and under this condition ripple and other input fluctuations have much the same effect on the grids of V_5 and V_6 as variations in output potential.

The 170-volt regulated output is developed across three resistors connected between the

combined cathodes of V_5 and V_6 and ground. The upper two resistors are shunted by a gaseous regulator tube, V_7, which holds the voltage constant across the two resistors; therefore, all changes in output occur across the third resistor, R_{14}. At the junction of the upper resistors, a connection is made to the control grid of V_3. Since the cathode of the control amplifier is held at a constant voltage by means of V_4, the full amplitude of any output variation appearing across R_{14} is coupled directly to the grid of the pentode to initiate the regulating action.

The following action results when the output swings above the desired 170-volt value. The grid of V_3 becomes more positive and causes the plate voltage to swing in the negative direction. This change is coupled to the combined grids of V_5 and V_6, thereby effectively increasing the negative bias level. This causes a greater voltage drop across the parallel triodes with a corresponding reduction in the output, which, by this action, is restored to the desired level. Decreases in the output cause a sequence of control actions in the opposite directions so that the result is an increase of the output to the correct level.

The 350-volt regulator contains a triode control tube, V_1 (fig. 9-3), instead of a pentode. The gaseous regulator V_4, which is common to this and the 170-volt circuit, maintains a constant cathode voltage on V_1. The stabilized output voltage appears across the resistors between ground and the cathodes of the dual triode, V_2. The action of the circuit in response to output changes is similar to that of the 170-volt regulator. A potentiometer, R_{12}, is shunted across one of the output resistors to provide a means of making initial adjustments of the grid voltage of V_1 and hence of the output level.

Voltage Adjustments

In addition to resistor R_{12} in the 350-volt regulator, the rectifier unit (fig. 9-3) contains five other variable resistors that are used for making voltage adjustments. Resistor R_7 is located in the primary of the power transformer, thereby permitting limited control of the a-c voltage applied to all the four rectifier circuits. Individual adjustments of the rectified voltages are made by means of variable resistors R_8 through R_{11}.

Test Equipment for Rectifier Units

Each missile power supply designed to be tested as a separate entity requires one or more units of special test equipment and also several items of standard Navy test equipment. Examples of specialized test equipment and associated instruments are illustrated in figures 9-4 and 9-5.

The set shown in figure 9-4 is used for testing the missile rectifier discussed in the preceding section. The auxiliary devices used in conjunction with the test set include an a-c power source that simulates the primary source in the missile; a group of resistors which simulate the load elements to which the various d-c voltages are applied; and a pair of tip-jacks for use in measuring the ripple in the rectifier outputs. Several cables needed to complete the operational setup are included in the items supplied with the test set.

The standard test instruments used with the power-supply tester complete the setup indicated in figure 9-5. The oscilloscope gives a means of making visual checks of waveforms and is used specifically to measure the quantity of ripple in the d-c voltages. The multimeter contains a vacuum-tube voltmeter (vtvm) and also an ohmmeter. The voltmeter must be capable of measuring both a-c and d-c potentials. It is employed in the initial setting up of the equipment and is also used in troubleshooting in the event that circuit faults are found to exist.

Figure 9-6 is a schematic of certain portions of the rectifier tester under discussion. The circuits shown are useful for illustrating representative tests and for indicating the fundamental checkout procedures. Switch S_1, the channel voltage selector, serves the following basic purposes: it selects the voltage to be tested, provides a means of connection to the applicable voltmeter, and inserts the proper multiplier into the circuit so that the same meter can be used for several voltage checks. It is interesting to note that the meter is not calibrated directly in terms of voltage, but rather in percentage. Thus, a reading of 100 percent indicates that the circuit under test is performing properly insofar as the

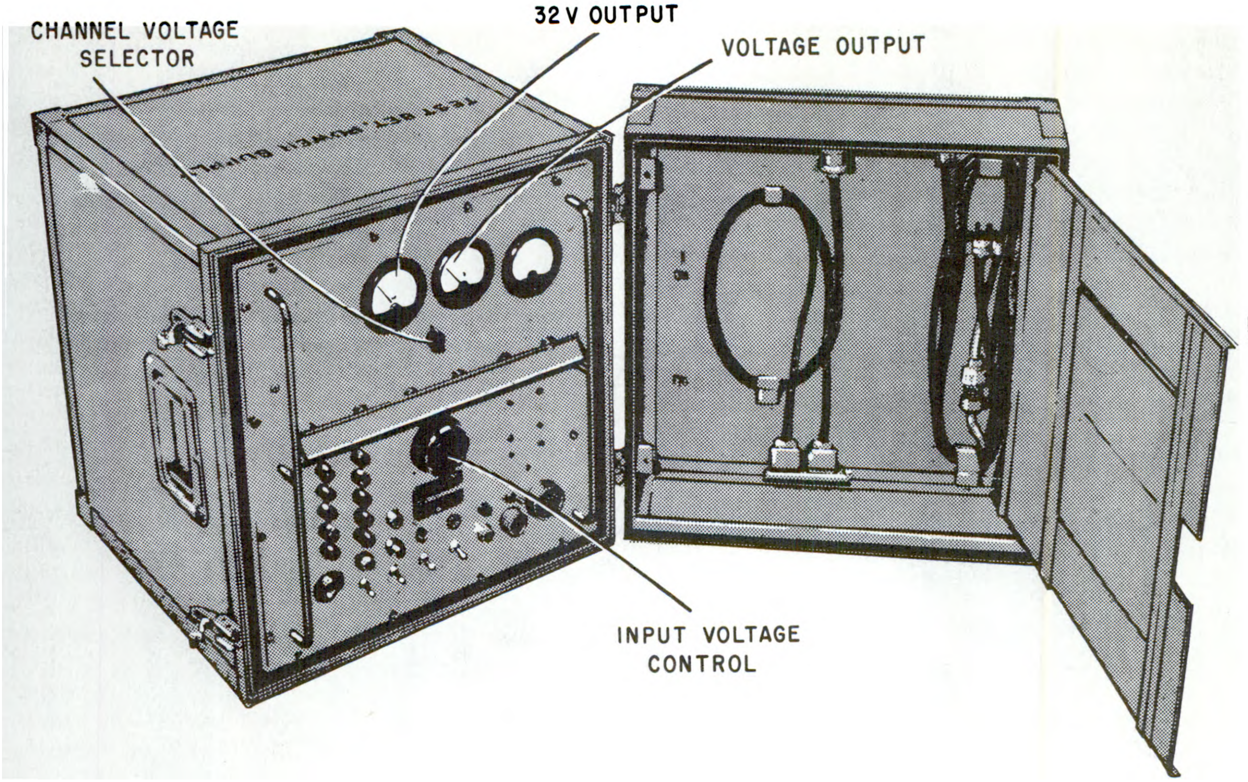


Figure 9-4.—Power-supply test set.

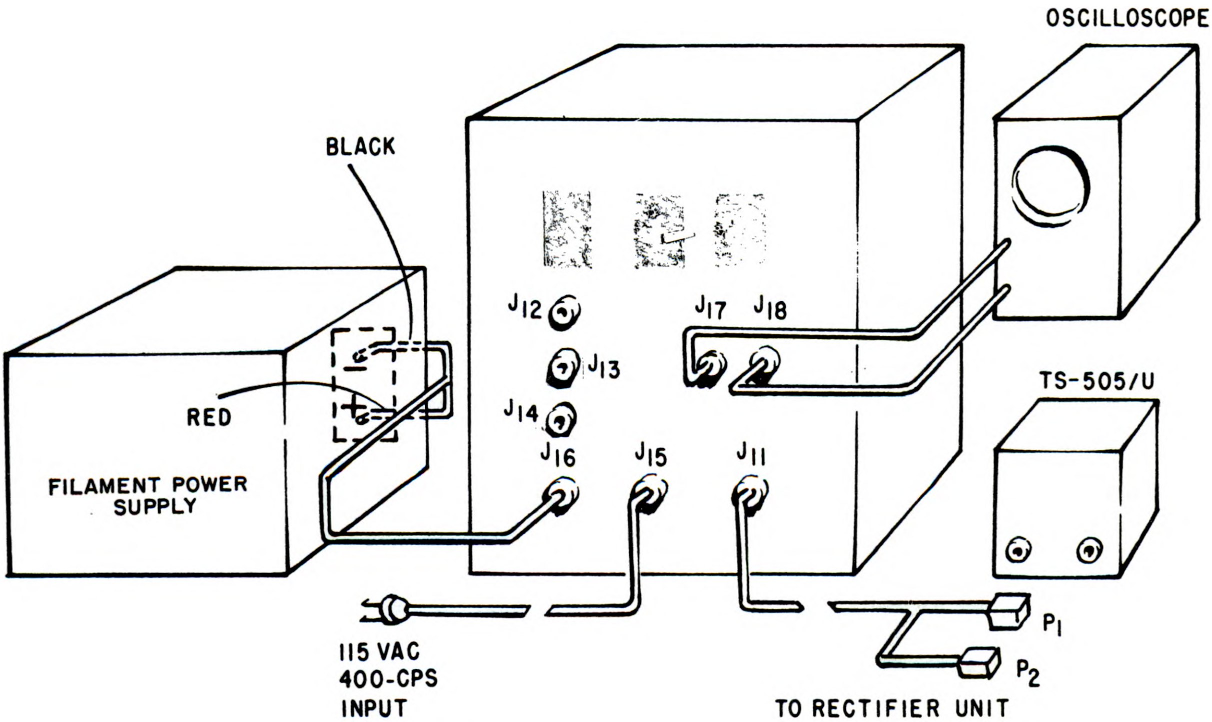


Figure 9-5.—Setup for conducting power-supply test.

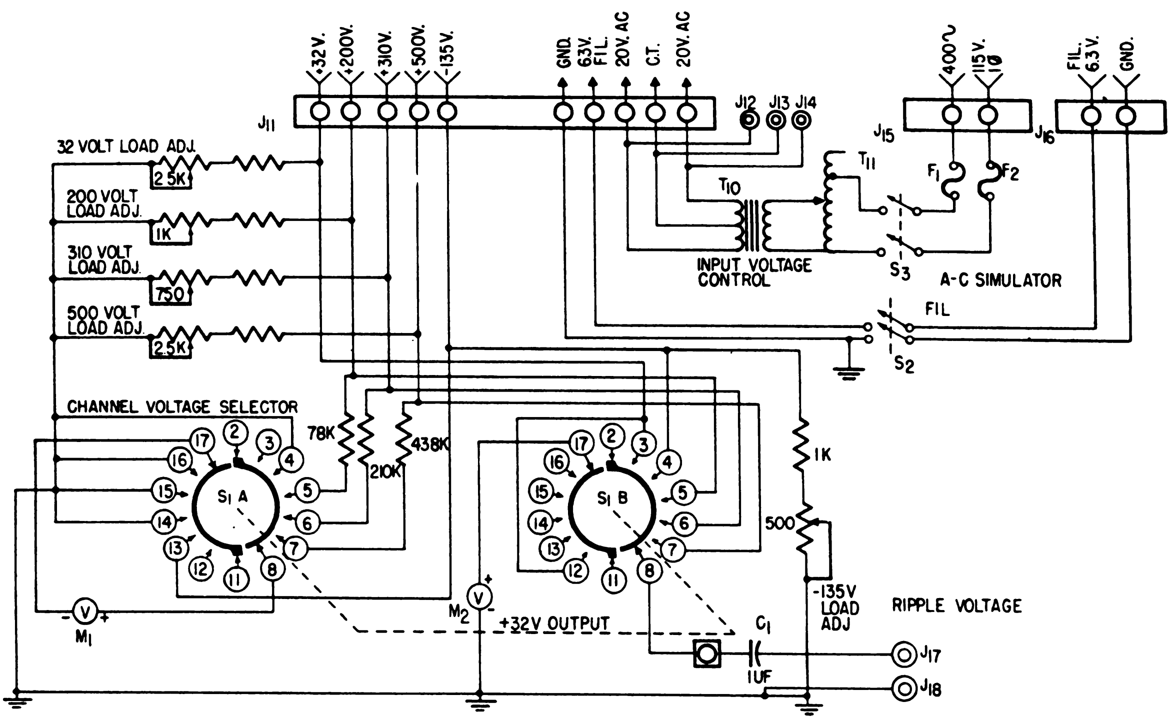


Figure 9-6.—Schematic diagram of typical power-supply test equipment.

output level is concerned. This type of calibration makes it easier and simpler to use the equipment since the output reading falls on the same mark on the meter dial for each test, and hence eliminates the need for numerous reference marks on the face of the instrument.

An additional circuit connection made by switch S_1 is that of coupling each output voltage under test through capacitor C_1 to the ripple voltage jacks, J_{17} and J_{18}. This is done so that any a-c component of the output may be observed and measured.

Switch S_2, a power switch, is used to route filament voltage from the power supply to the missile package under test. Switch S_3 connects the primary a-c input power to the variable transformer T_{11}. The input voltage control is a variac which is adjusted to give the proper amplitude of the a-c voltage applied to the particular package under test. This voltage is measured with the vacuum-tube voltmeter and, when adjusted correctly, simulates the a-c level of the primary power source in the missile. The test points for making this adjustment are indicated in figure 9-6 at J_{12}, J_{13}, and J_{14}.

Two meters are employed to measure the five voltages produced by the rectifier. Meter M_2 indicates the output of the 32-volt circuit when switch S_1 is in position 2. Meter M_1 measures the remaining voltages in other positions of the switch.

Note that the selector switch S_1 is composed of two wafers, each of which is split into two sections. The "A" wafer selects the voltage to be tested and also functions as a polarity reversing switch; in addition, it inserts the required multiplier resistor. The polarity reversing feature is employed so that both positive and negative voltages may be measured on the same meter.

The "B" wafer of S_1 (fig. 9-6) brings the 32-volt meter into the circuit when required, and simultaneously routes the voltage under test to the ripple-voltage jacks. Between each of the input terminals and ground, a fixed resistor and a variable resistor are inserted to simulate the load placed on the supply by the missile circuits. The resistors remain in the output circuits as long as the power supply is operating, thus removing the possibility of running the unit without load.

Rectifier Test Procedures

All information required for complete checkout as well as for adjustment and repair of a particular missile unit is contained in the applicable *Handbook of Assembly, Checkout, and Service Instructions.* A summary of the information pertaining to the rectifier unit described previously is given in the following pages. This information, as presented in the handbook, is divided into four sections: general instructions, a list of tools and test equipment required, preliminary instructions, and detailed checkout procedures.

GENERAL INSTRUCTIONS

This section states the purposes of the checkout and also explains the proper use of the checkout instructions:

1. The purposes of the checkout are to ascertain whether the power supply is performing according to specified standards; and if it does not, to isolate the trouble to a single assembly or circuit so that corrective measures can be taken.
2. The checkout procedure is presented as a series of operational steps. With each step, the following items are designated: the test point or points concerned; the proper connections of the test equipment; the positions of the test-set controls; indications of normal operation; and possible causes of and remedies for abnormal indications.
3. Test points, at which test-signal outputs are to be taken, are indicated by numerals in starred circles. In some cases, several test points are designated in a single circuit to provide test data corresponding to various levels of circuit detail.
4. The directions pertaining to abnormal indications may or may not be specific at a particular step. If specific information can be given, the possible causes of trouble are indicated as being in a certain subassembly or part, which can then be replaced. If the area of trouble is in a complex circuit, the general location of the fault may be indicated, and the specific trouble must then be isolated by basic troubleshooting methods. If specific information cannot be given, the operator is directed to proceed to subsequent steps which isolate the trouble further and which eventually lead to more detailed information.

TOOLS AND TEST EQUIPMENT REQUIRED

The tools required are those in common use in electronics shops together with any special tools needed for work on circuits containing miniaturized parts. (Examples of the latter type are given in chapter 14, *GF 3 & 2.)* The necessary test equipment includes the specialized test set, a source of filament power, and the instruments shown in figure 9-5 (oscilloscope and multimeter).

PRELIMINARY INSTRUCTIONS

Prior to connecting the rectifier unit to the test set, several preliminary adjustments must be made and certain precautions taken. All power switches are turned off, the a-c simulator switch is turned off, and the input-voltage control is placed in the minimum-voltage position. Then, after removal of the covers of the rectifier unit, connections are made to the test set as shown in figure 9-5. The operator then proceeds according to the following directions given in the handbook:

1. Turn on the filament power-supply and adjust the output to 7.0 volts. (The specified output is generally slightly in excess of the rated filament voltage to allow for line voltage drops; for example, approximately 7.0 volts are applied to filaments rated at 6.3 volts.)
2. Allow a one-minute warmup period to permit the filament supply to stabilize; then apply filament voltage to the unit by throwing the appropriate switch on the test-set panel. Allow another one-minute warmup before applying plate voltage.
3. Connect the vacuum-tube voltmeter between jacks J_{12} and J_{14} (fig. 9-6). Turn the a-c simulator switch to the on position and adjust the input-voltage control until the specified value (in this case, 20 volts, a.c.) is indicated by the voltmeter. The equipment is then properly set up for the checkout procedure.

CHECKOUT PROCEDURES

Authorized checkout procedures are usually presented in missile handbooks in tabular form. As an example, consider table 9-1,

which contains the first three operational steps for testing the rectifier unit under consideration. The first step involves the 32-volt regulated output. The checks are made by varying the input and measuring the resulting output changes and also by measuring the quantity of ripple voltage. Acceptable performance is indicated when the results come within the tolerances given in column four of the table. The fifth column gives the procedure in the event of zero output and out-of-tolerance results. The second and third steps pertain to the minus 135- and 200-volt unregulated circuits, respectively. The checks made on the remaining rectifier circuits are conducted along similar lines.

ADJUSTMENT OF PRIMARY VOLTAGE CONTROL

In addition to the checkout procedure, instructions are given in the handbook for precision adjustment of the primary voltage control (R_7 in fig. 9-3). The adjustment is made with a resistance bridge while the rectifier unit is disconnected from the test equipment. The bridge elements must be such that balance occurs when the unknown resistance arm is exactly 0.375 ohms. To make the required setting, the bridge is connected to pins A and C of J_2 (fig. 9-3), and R_7 is varied until a null indication is given by the meter in the bridge circuit.

Table 9-1.—Rectifier checkout procedures.

Step	Test point	Test equipment control positions	Normal indications	Possible cause of abnormal conditions
1	1*	Channel voltage selector on plus 32. Input voltage control adjusted to read 20 to 24 volts on vtvm.	32-volt output meter reads 32 v. ± 1.0 v. Does not vary more than 0.5 volts as input is varied. Oscilloscope reads less than 0.5 v. peak-to-peak ripple.	R_5 out of adjustment. Adjust for plus 32 v. If no output, check V_8 and associated components.
2	2	Set channel voltage selector on -135 v. Adjust "input voltage adjust" for 22 v.	"Voltage output" meter reads 100% ± 5% as input is varied. Ripple reads less than 1.0 v., peak-to-peak.	R_{11} out of adjustment. Adjust for 100%. If no output, check V_{15} and associated parts; also check T_1.
3	3	Set channel voltage selector on +200 v.	"Voltage output" meter reads 100% ± 5%. Oscilloscope reads less than 2.0 volts peak-to-peak ripple.	Maladjustment of R_9. Adjust for 100%. If no output, check V_{12}, V_{14} and associated parts.

*Major test points are indicated by numerals within star-shaped figures; secondary check points by letters enclosed in circles.

QUIZ

1. (Refer to fig. 9-1.) The output of the generator remains almost constant under varying loads but varies directly with changes in applied
   a. d.c.
   b. a.c.
   c. a.c. or d.c.
   d. all the above are correct

2. The output taken off the commutators of the dynamotor is
   a. filtered d.c.
   b. pulsating d.c.
   c. low a.c.
   d. high a.c.

3. (Refer to fig. 9-3.) If pin 1 (plate) of V_3 were to open, the probable result would be that the 170V output would
   a. decrease
   b. be normal
   c. vary above and below 170 volts
   d. increase

4. (Refer to fig. 9-1.) The negative 100V is maintained at a constant level by
   a. V_6
   b. V_5
   c. V_4
   d. V_3

5. (Refer to fig. 9-1.) The purpose of V_6 is to
   a. provide further regulation of klystron repeller voltage
   b. provide further regulation of -100V
   c. provide further regulation of -100V and -200V
   d. none of the above are correct

6. (Refer to fig. 9-1.) Which of the components in the -200V regulated circuit acts as a protective device to maintain the repeller plate voltage within safe limits during extreme changes in the power supply load?
   a. V_2
   b. V_5
   c. V_3
   d. V_6

7. (Refer to fig. 9-3.) The positive 350V and 170V outputs are not being regulated. A possible cause of trouble is
   a. V_1 inoperative
   b. V_{10} inoperative
   c. V_7 inoperative
   d. V_4 inoperative

8. In the system illustrated in figure 9-1, the voltage doubling is due to the alternate
   a. charging of C_7 and C_8
   b. current flow through R_5 and R_6
   c. charging of C_5 and C_6
   d. conduction of V_4

9. In figure 9-3, the purpose of the tube V_8 is to
   a. regulate the 32V output
   b. provide a reference potential for V_9
   c. supply B+ to V_9
   d. regulate the -135V output

10. In figure 9-3, the unbypassed screen grid of V_3 provides
    a. regulation of the +310 output
    b. ripple cancellation of the +310V output
    c. ripple cancellation of the +170V output
    d. constant B+ for V_3

11. In figure 9-3, the reference voltage for the control tube of the +350V regulator is established by
    a. V_3
    b. V_7
    c. V_5 and V_6
    d. V_4

12. When testing missile power supplies, an oscilloscope is used specifically to measure the
    a. quantity of ripple
    b. percentage of regulation
    c. output voltage amplitude
    d. changes in power supply load

13. In figure 9-6, the meters are calibrated to indicate __________ of proper output level.
    a. amplitude
    b. percentage
    c. ripple
    d. percentage of regulation

CHAPTER 10
MISSILE WING SERVOMECHANISMS

Servomechanisms have been used for many years for controlling machines and processes in industry; as control devices in calculating machines; for steering ships; and in fire-control systems of guns in aircraft, on ships, and on the ground. Servo equipment is also an essential part of any guided missile, in which it provides the means of steering the weapon toward the target and stabilizing it in flight. Servo units are employed in missiles of all types—active, semiactive, beam-rider, command, and combinations of these. They respond to up-down and right-left commands produced by the guidance equipment; and operate the wing surfaces to control the missile in pitch and yaw, and in some cases, in roll.

Of the many varieties of closed-loop servo systems in use, electrohydraulic and electropneumatic are the predominant types employed in air-launched missiles. These systems are well adapted for missile applications since they are capable of storing and releasing large amounts of energy under conditions of accurate and positive control. They provide high power gains so that large amounts of power are controlled by a few watts; and they make it possible to develop and sustain the large forces required to deflect the control surfaces of supersonic missiles.

A basic survey of servomechanisms is given in chapter 7, *GF 3 & 2*, NavPers 10379, in which fundamental components and operating principles are discussed. In this chapter, the subject matter is largely confined to servo testing. The first section treats the general principles of the test procedures used; subsequent sections describe a representative wing-actuator unit, the associated test set, and the types of tests performed with the equipment described.

Testing Wing Servo Units

Wing servomechanisms, which contain electronic and mechanical devices of considerable complexity, are subject to part failures and malfunctions which can result in improper operation of the entire control section. When major systems testing reveals malfunctions in these units, they are removed from the missile and given further tests with special equipment to assist in making the necessary adjustments or repairs.

In typical test procedures, the wing units are checked in the operating condition by evaluating performance in response to various types of inputs. The function of the wing-control units is to produce mechanical output positions of the load member in accordance with electrical command signals. In most cases, the normal operating input is a low-frequency, low-amplitude voltage; and in all cases, the load member is a wing surface. The wing is significantly massive and is subjected in flight to large amplitude disturbance forces by the buffeting of the airstream.

The principal requirement of the wing unit is that it respond quickly and accurately to applied commands while, at the same time, resisting external wing forces applied by cross-wind or as a result of skid. In practice, testing is conducted by checks of response to electrical commands; and satisfactory responses to disturbance inputs can usually be assumed if proper operation has been established in the former case.

For test purposes, the wing shaft is monitored from data produced by feedback or telemetering potentiometers installed in the unit or by some other suitable form of transducer attached to the wing shaft. The monitoring device may be a meter, a visual recorder, or a cathode-ray tube of a wing-position indicator.

Because of the many basic similarities in the construction and operation of wing servo units, there are also many similarities in the malfunctions they develop. Each unit contains electronic, electromechanical, and hydraulic or pneumatic components, and each has at

least one feedback loop. Hence, the expected departures from normal performance are similar in nature, magnitude, and tolerance. As a result, this entire class of equipment is compatible with common methods of testing and test equipment. These methods are discussed in the following pages and a representative example of test equipment is illustrated after a discussion of the principal characteristics upon which many of the tests are based.

DEFINITIONS OF SERVO CHARACTERISTICS

The significant characteristics employed in evaluations of position servo components may be divided roughly into two classes—static and dynamic. The former includes sensitivity, dead zone, minimum motion, and discontinuity. The principal dynamic characteristic is the transient response to a step function which can be specified in terms of overshoot and settling time.

Static Characteristics

By sensitivity is meant the static output of the servo as a function of input. In missile equipment, this relation is essentially linear over the entire range of operation and can be specified in terms of degrees of wing deflection per volt of input.

Dead zone is a measure of the degree of definition of the output as a function of the input, and may be specified as the maximum variation in input with no corresponding output change. For example, the dead-zone figure for an output deflection of 3 degrees may be 0.1 volt, which means that input changes less than the latter amount will produce no change in wing deflection. Dead zone may vary over the range of operation and should be checked at different points.

Minimum motion, which is closely related to dead zone, is defined as the change in output in response to a change of input just sufficient to cause it.

Servo discontinuity is measured by the difference of the outputs resulting from the same input value, when the latter is approached from different directions. Consider, for example, the following action of a one-degree-per-volt wing actuator. A command signal of 8 volts is applied, causing the wing to deflect to a position 8 degrees from streamline. An additional 2 volts of input are injected, and the wing deflects to 10 degrees. Then the 2-volt increment is removed; and the wing, which should return to the 8-degree position, reverts instead to 8.5 degrees. In this instance, the unit is said to exhibit discontinuity, since the same input (8 volts) did not produce the same output position in both cases.

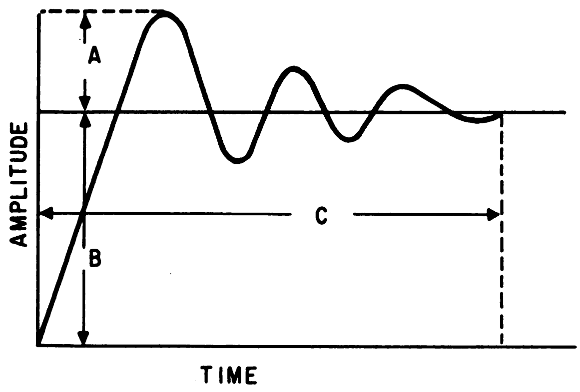


Figure 10-1.—Overshoot and settling time.

Dynamic Characteristics

The significant characteristics employed in testing the ability of a wing servo to reproduce varying inputs are overshoot and settling time. These quantities can be evaluated by subjecting the unit to a step function input, or an instantaneous jump in voltage from zero to some appropriate level, as indicated in figure 10-1. Overshoot is a measure of the degree of instability in the system, and can be defined in terms of the quantities A and B in the figure. It is the maximum magnitude of the first cycle of damped oscillation (A) following the step input expressed as a percentage of the final output value (B). Settling time, represented by C, is a measure of the duration of significant error following a step change of input. It may be specified as the maximum time required for the error to reduce and remain below a stated percentage (usually 5 percent) of the final value.

Position servos are ordinarily designed to be somewhat oscillatory following step inputs in order to effect speedy response. Limits must be imposed on the maximum amplitude, however, or else the system may develop sustained "hunting" when responding to normal input variations during operation. In addition, the oscillation must decay in a reasonably short time or the purpose of obtaining speedy response will be lost.

METHODS OF TESTING

In chapter 6 of this course, it is stated that there are two general methods used in testing servo systems and units. One is based on frequency-response measurements; the other involves transient analysis of the responses to step-input signals. In tests of missile wing-control equipment, one or both of these methods may be applied. Transient analysis is usually the more desirable of the two for a number of reasons. The time consumed in conducting the checks is generally less; and the equipment needed for supplying test inputs is comparatively simple. An even greater advantage lies in the fact that the results of transient tests can be displayed and evaluated with much greater ease and objectivity. The motions of the output member can be translated into electrical data which can be presented on the screen of an oscilloscope. The latter, when equipped with a transparent mask inscribed with suitable tolerance markings, then provides a means for making rapid and accurate estimates of the quality of performance and for detecting immediately the results of out-of-tolerance functioning.

Examples of the information provided by the two test methods are given in figure 10-2. The graphs on the left represent the response of a wing unit to a band of equal-amplitude, sine-wave inputs. At each different frequency, the gain and phase-shift values are plotted so that two curves result. Four sets of curves are shown, each of which corresponds to a specific setting of one of the unit parameters (such as inertia or damping).

Following each of the four frequency-response measurements, a step input is then injected into the same wing unit under the same condition of the significant parameter. The resulting outputs are displayed on a cathode-ray oscilloscope, as shown in (B) of figure 10-2 in the right-hand column. It is important to note that for each change in the servo parameter, a corresponding change appears in both the frequency-response curves and in the oscillograms.

With the methods illustrated (fig. 10-2), designers derive objective data representing upper and lower tolerance limits for use in the design of wing-position indicator masks of the type mentioned previously. Examples of these data are shown in figures 10-3, 10-4, and 10-5, which pertain to upper tolerance limits, lower tolerance limits, and tolerance areas, respectively.

If the parameters of a particular servo unit are set in a laboratory so that the performance of the device comes up to the specified upper tolerance limits, the frequency and transient responses can then be plotted as shown in figure 10-3. The curve in (A) is a gain-versus-frequency graph; (B) is a plot of phase shift-versus-frequency; and (C) is an oscillogram of the transient following the application of a step-function test input. (The latter figure indicates that the unit is in the underdamped condition, which is assumed to be the optimum value for the particular case being considered.)

Similarly, if the parameters which determine servo performance are changed so as to result in operation which borders on the lower limits of acceptable performance, the same frequency and transient tests can be performed to give the types of data illustrated in figure 10-4.

The curves in figures 10-3 and 10-4 can be combined to indicate tolerance areas, as shown in figure 10-5. Thus, any servo unit of the same type with gain characteristics falling within the shaded area in (A) would be considered as having acceptable gain. The area in (B) defines acceptable phase-shift characteristics; while (C) indicates the area of acceptable transient response. The exact transient response for optimum performance varies with the specific application of the unit in question; but in almost every case, desired response lies in the region between underdamped and critically damped operation, the degree of damping being the factor which determines the time required for the output to reach a new position following a step change of the input. Note that the area in (C) is determined in the vertical dimension by the amplitude of oscillation of the output and in the horizontal dimension by the settling time. The use of this type of information is illustrated in further detail in the section of the chapter entitled "Wing Servo Tests and Adjustments."

Typical Wing Position Servo Unit

The general test methods described above are used with units of the type illustrated in figure 10-6. This device consists principally of a servo amplifier and a hub-section assembly. The circuitry of the amplifier is discussed in chapter 8 of this training course and only

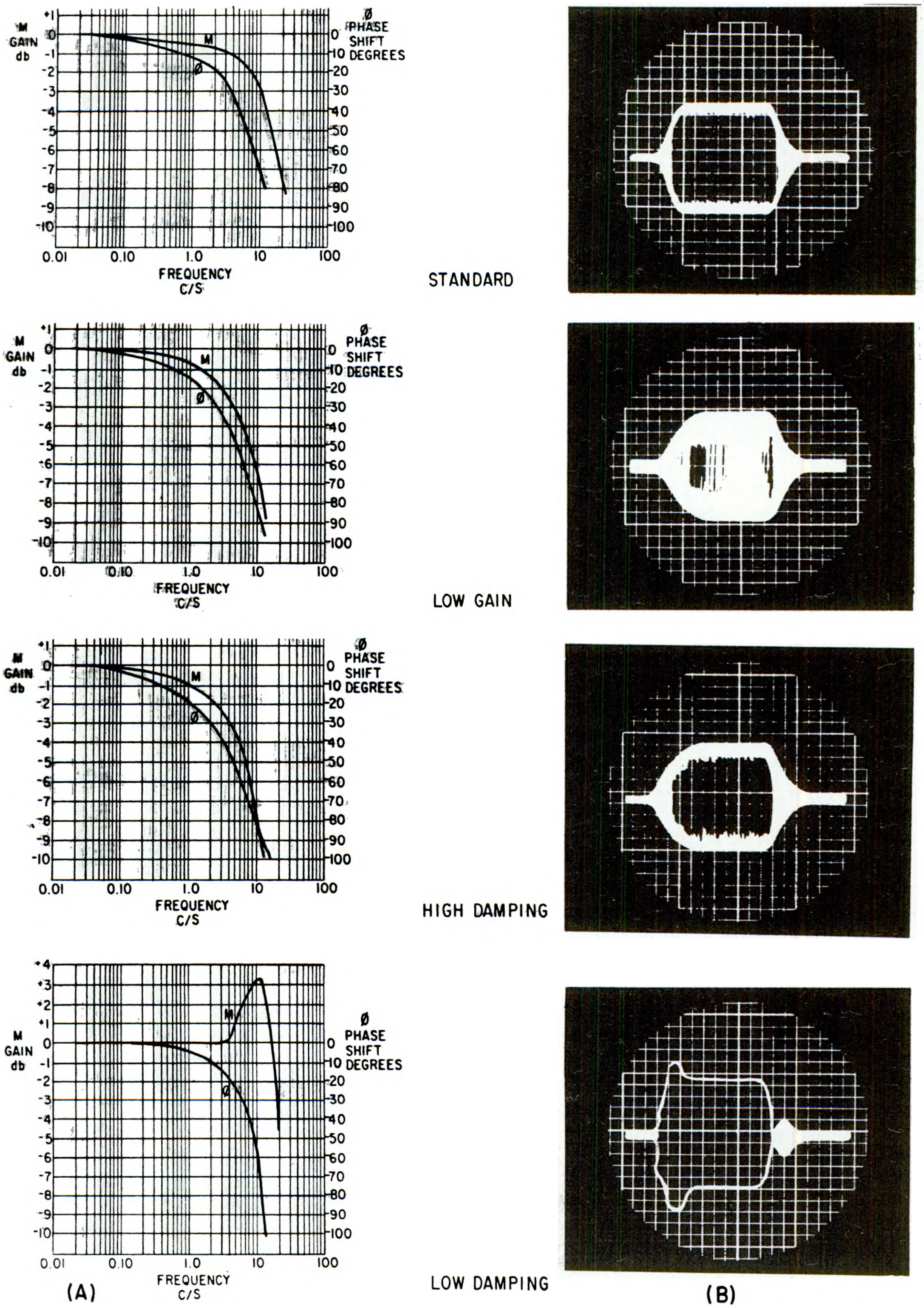


Figure 10-2.—(A) Frequency-response curves; (B) oscilloscope presentation of step-input response.

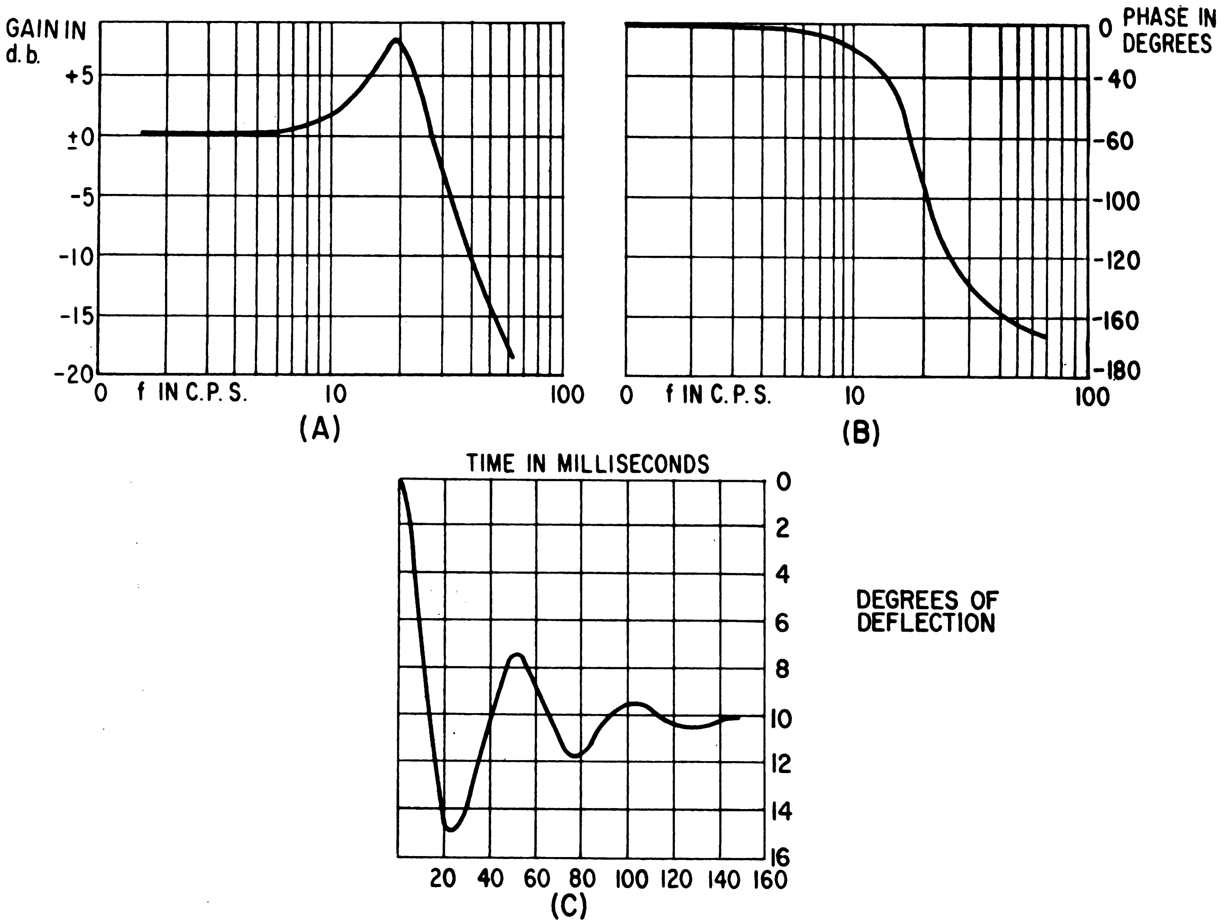


Figure 10-3.—Upper tolerance specifications.

those functions involved in testing need be reviewed here.

The phase inverter (fig. 10-6) converts single-ended, yaw-command signals into double-ended (push-pull) signals required for operation of the phase-sensitive demodulator circuit. The input grid circuit of the phase inverter contains a summing network in which both wing feedback voltages and the incoming command signals are combined.

The demodulator changes the double-ended, a-c signals into pairs of d-c output voltages, which are proportional in amplitude to the amplitudes of the corresponding a-c inputs. The relative polarities of the d-c outputs are determined by the phase relationship between the input command signals and the reference-oscillator voltage. The final stage of the servo amplifier consists of a pair of tubes connected in push-pull which provide the required power gain for operating the solenoids in the hub section.

The yaw hydraulic servo in the hub section (fig. 10-6) contains a valve stroker, which converts electrical signals into mechanical motion of a control valve. The latter regulates the flow of hydraulic fluid into the cylinder of the wing actuator, which positions the yaw wings by means of mechanical linkages.

The two coils in the valve stroker assembly serve as the load impedance of the push-pull power amplifier. The coils operate an armature, which is center-suspended by a torsional spring. The armature is linked to the spool of the control valve by a thin wire strut. When equal currents flow in the coils, as is the case when zero error exists in the missile servo system, equal magnetic forces center the armature. This, in turn, holds the valve stem in the centered, or neutral, position. When the valve is in neutral, hydraulic fluid can flow neither into nor out of the cylinder, and the piston is held in a fixed position by the fluid in the cylinder.

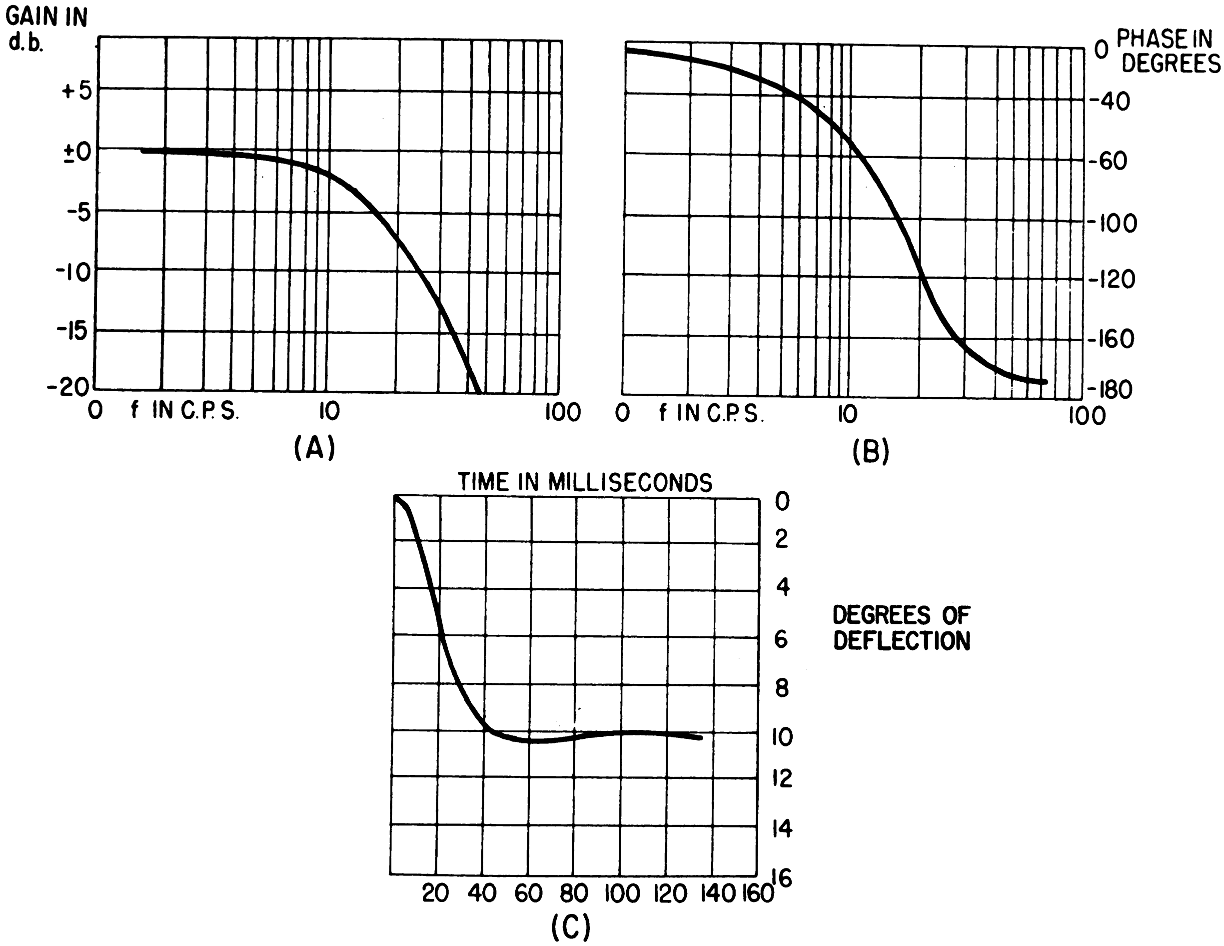


Figure 10-4.—Lower tolerance specifications.

When an error voltage in the servo system causes a differential current in the stroker coils, the magnetic forces at either end of the armature become unequal. The resulting armature deflection moves the valve from the center position, and hydraulic pressure is applied to one side of the piston while fluid from the opposite end of the cylinder is forced to flow into the exhaust passage. As the piston moves in response to the hydraulic pressure, it moves the wing and also the wiper of a feedback potentiometer linked to the opposite end of the piston. The potentiometer supplies a feedback voltage proportional in amplitude to the wing displacement. This voltage is applied to the servo amplifier, where it is subtracted from the command signal.

The piston (fig. 10-6) moves until it reaches a point where the feedback voltage is equal to the command signal. At this point, the error in the servo system becomes zero, the control valve plunger returns to the neutral position, and the wing remains in the deflected position until another command is put into the system. Armature limit switches are installed to restrict armature travel to a few thousandths of an inch, thereby eliminating the possibility of developing oscillation, which might otherwise result when strong signals are applied.

In the discussion of transient response of servos to step inputs, it was stated that oscillation of the output device tends to damp out due to frictional forces present in the system. However, if the output motion should lag the input by a time interval sufficiently great, the feedback may act regeneratively instead of degeneratively and cause the system to develop strong oscillation.

There is always some amount of time delay in a servo system resulting usually from lags in the output device and the controller. In order to compensate for this delay, networks are inserted in many units of the type shown in figure 10-6 to introduce phase leads. In

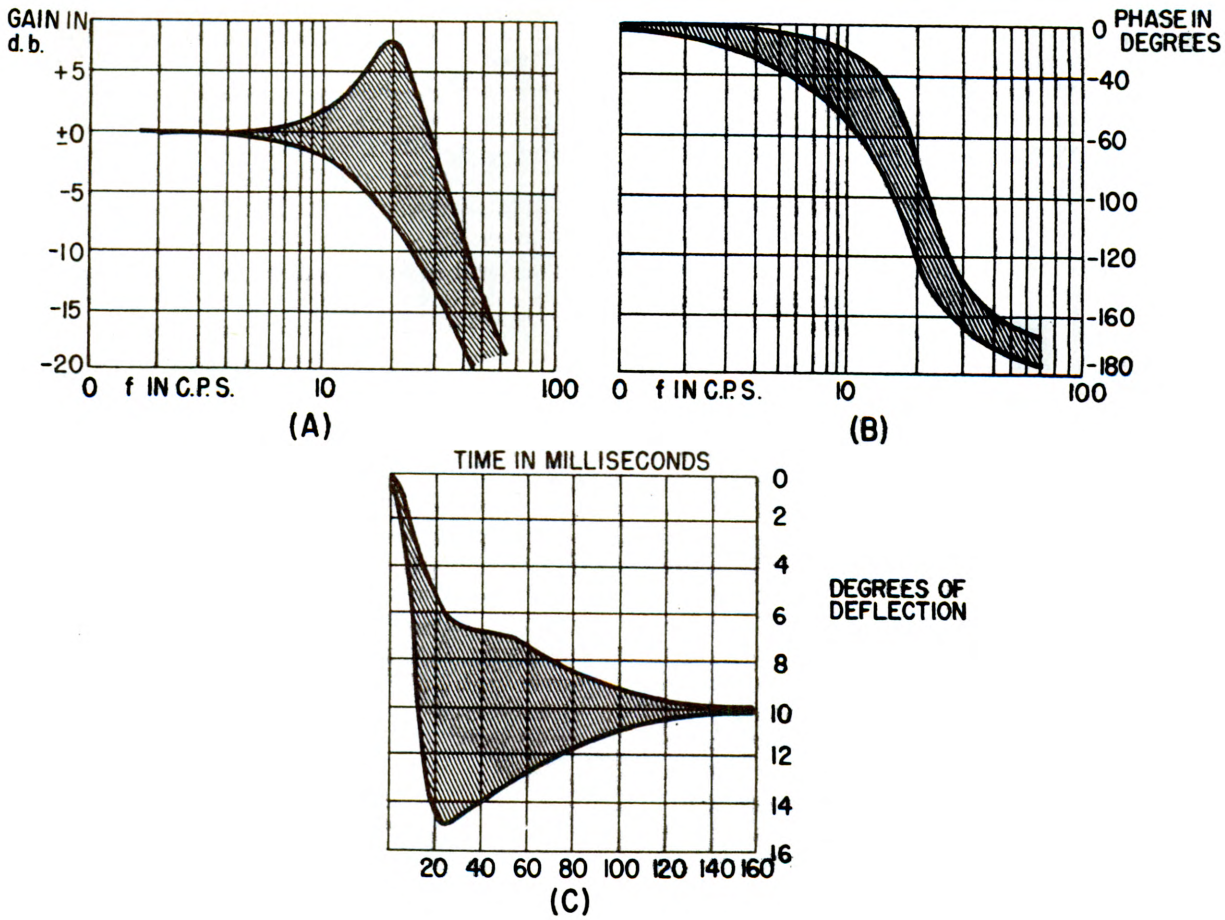


Figure 10-5.—Composite tolerance curves.

the usual form, lead networks are resistor-capacitor combinations designed to produce sufficient phase lead in the command signals to compensate for inherent delays in the system, and thereby prevent oscillation. The method of connection and general characteristics of networks of this type were discussed in chapter 6 of this training course.

The Servo Test Set

The operation of wing servos of the type described above is tested and evaluated by means of test equipment of special design. An example is the test set illustrated in block-diagram form in figure 10-7. The unit, which utilizes the transient-response method of testing, contains a signal generator section for supplying test inputs and an oscilloscope for displaying the resulting output responses.

The command signal produced by the signal generator may be either a simple square wave, or an a-c carrier modulated in amplitude by square pulses. The response of the servo unit is displayed as a stationary oscilloscope pattern, in which time values are represented on the horizontal and output amplitude on the vertical axis. A properly calibrated plastic mask is placed over the face of the cathode-ray tube to provide reference data for making quantitative transient response measurements. Additional masks suitably engraved for other missile servo units are available, thereby extending the range of application of the set to include more than one type of equipment. In addition, a mask engraved with a uniform grid is included in the equipment and is used for general transient response measurements.

The signal generator section of the test set (fig. 10-7) consists of a square-wave generator, a d-c amplifier, and a modulator circuit. All

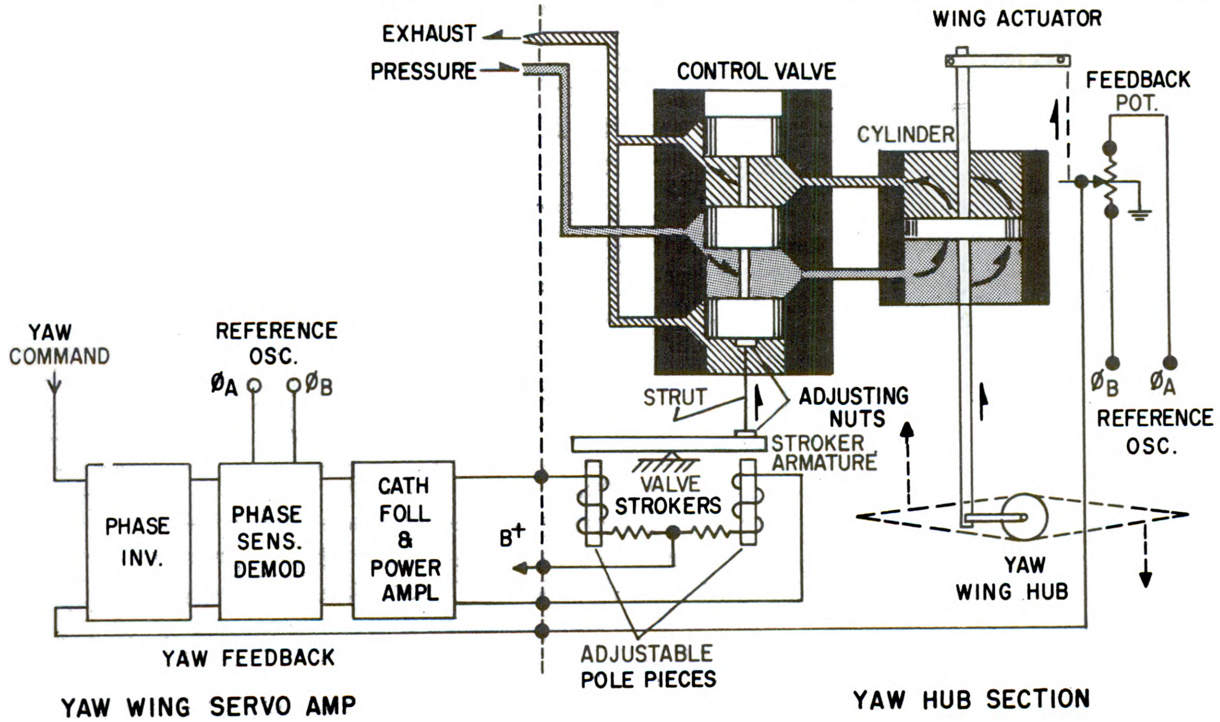


Figure 10-6.—Yaw wing position servo unit.

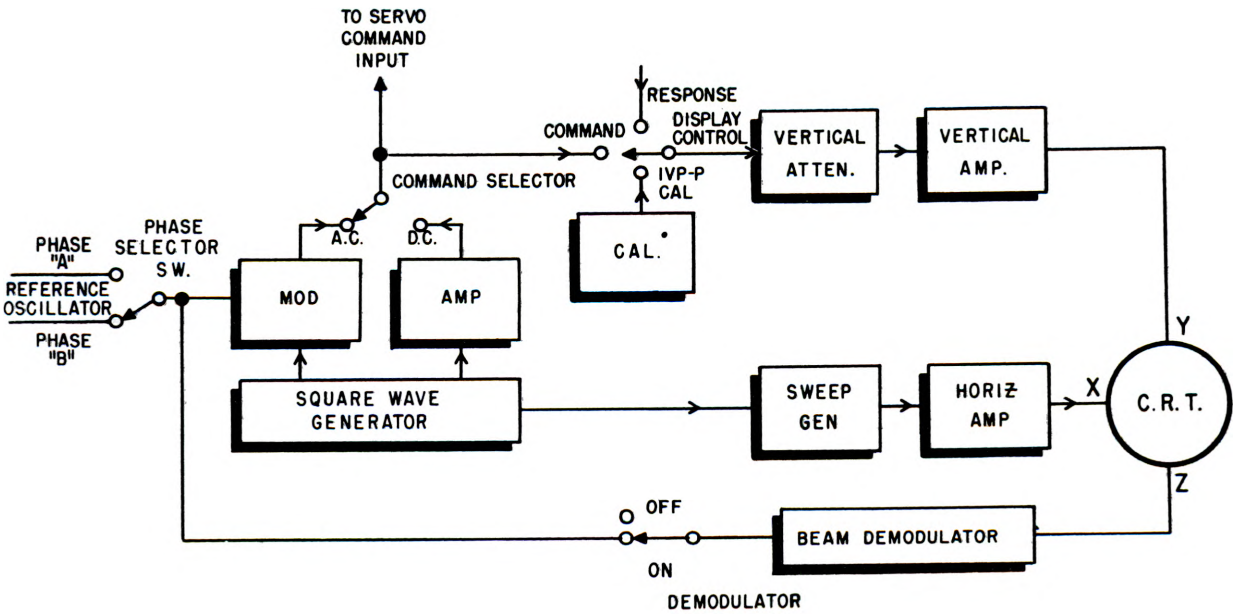


Figure 10-7.—Block diagram of servo test set.

timing functions are controlled by the square-wave generator, a free-running multivibrator equipped with three sets of R-C timing networks. These are designed to produce waves with periods of 0.1, 1.0, or 10 seconds. The desired value may be selected by means of a switch.

One output of the square-wave generator is applied to the amplifier circuit (fig. 10-7) which provides the means for clamping the bottom of the signal at ground potential. The amplifier also contains a potentiometer control for adjusting the signal amplitude applied to the command selector switch. The output is controllable between 0.01 and 5.0 volts, peak-to-peak, with a zero-volt, d-c base.

Another output of the square-wave generator is applied to the modulator circuit (fig. 10-7), where it is used to gate the reference oscillator on and off during a-c operation of the test set. The reference oscillator can be either part of the missile system under test or a separate signal generator with a frequency range of 300 to 3,000 c.p.s. The phase of the reference-oscillator output is selected to control the direction of wing movement. The amplitude of the gated a-c wave is controlled between 0.005 and 2.0 volts (peak-to-peak) by means of a potentiometer in the modulator circuit.

The beam demodulator (fig. 10-7) recovers the modulation from the signal being displayed without introducing objectionable dynamic lags by virtue of operating on the Z axis (intensity) of the display. With the demodulator switch in the ON position, the reference oscillator signal is fed to the demodulator. The positive peaks of the reference-oscillator signal are converted into sharp pulses of short time duration to gate the CRT beam.

The oscilloscope section of the test set (fig. 10-7) consists of conventional vertical and horizontal deflection circuitry. Inputs for the vertical deflection amplifier circuit are selected by the Display Control. The Command position applies the signal-generator output signal; the Response position applies the external signal; and the 1V Peak-to-Peak Cal position applies an internally generated calibrating voltage. The vertical deflection circuit may be considered as consisting of (1) a resistive step attenuator, (2) a voltage calibrator for checking vertical sensitivity, and (3) a high-gain, wide-band, push-pull, voltage amplifier for increasing the amplitude of low-level signals for suitable display on the CRT screen. The horizontal sweep circuit is comprised of a sweep generator which provides a sawtooth sweep internally synchronized to the square-wave generator and a horizontal amplifier which develops the necessary push-pull horizontal deflection voltage.

Wing Servo Tests and Adjustments

The interconnections of the servo test set and the yaw wing unit during checkout of the latter are indicated in the functional block diagram shown in figure 10-8. To prepare the setup, the operator connects the input signal leads to the input jacks on the wing unit and completes the necessary connections between the feedback potentiometer and the cathode-ray wing-position indicator. He then connects the external hydraulic power-supply lines and the leads from the electrical power supply.

The test equipment is then calibrated in accordance with instructions given in the handbook. The vertical positioning control of the oscilloscope is adjusted to center the trace and the signal generator amplitude control is adjusted so as to give a one-division excursion on the screen.

STATIC AND DYNAMIC TESTS

Static sensitivity is tested by observing the amplitudes of the oscilloscope patterns for each of several step inputs consisting of square waves with ten-second periods. The pulse duration in this case is sufficiently long so that steady-state output readings can be presented on the screen. Dead zone is measured by applying square-wave inputs with amplitudes specified in the handbook. The resulting wing deflections are indicated by the oscilloscope, and for satisfactory performance, must show perceptible motion corresponding to each half cycle of applied signal. Motion of the wings in either direction can be produced by switching the phase of the reference oscillator by means of a selector switch located on the test-set panel.

Dynamic performance is evaluated by applying small- and large-amplitude step inputs and comparing the resulting wing deflections with acceptable values. The step inputs consist of a series of square pulses, the duration and spacing of which are great enough so that the transient following each step has subsided

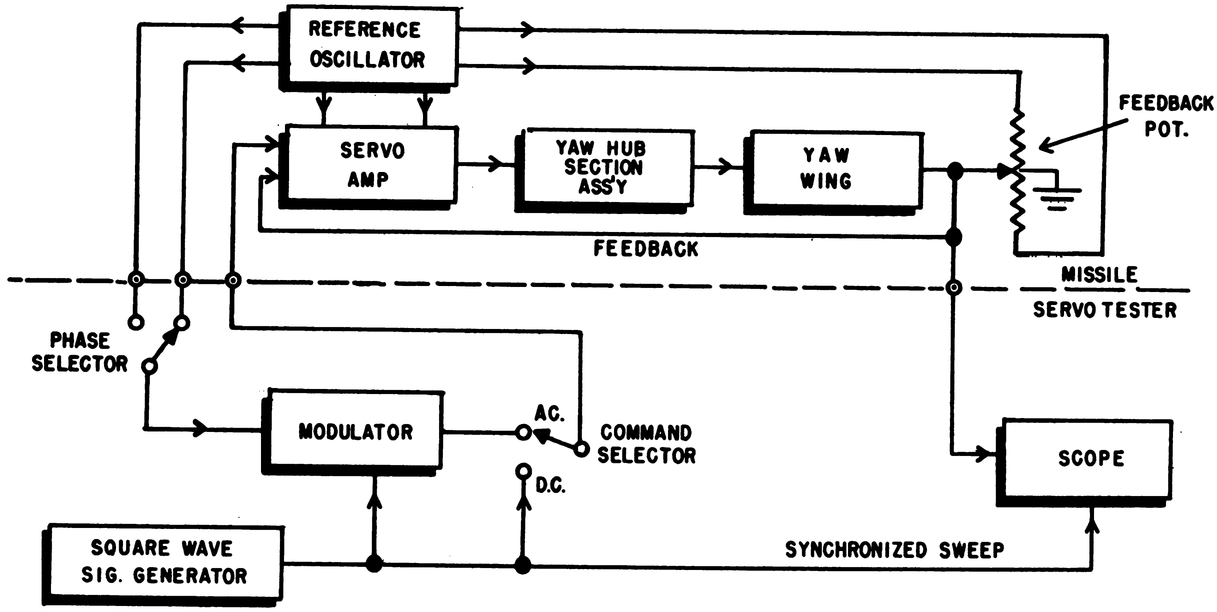


Figure 10-8.—Functional block diagram of servo tester.

before the next step begins. The wing deflections are monitored by the oscilloscope in the wing-position indicator. The oscilloscope screen is equipped with a transparent mask inscribed with appropriate tolerance markings based on the specifications of the unit under test. The small and large transient errors require the use of separate masks, since small-step response differs from large-step action because of nonlinearities in the operation of the unit.

The drawing in (A) of figure 10-9 represents the tolerance area marked on the transparent screen of the CRO tube. Satisfactory response is indicated when the oscilloscope trace falls entirely within the tolerance limits, as shown in (B). Unsatisfactory response is indicated when the trace overshoots the pattern, either vertically, as in (C), or horizontally, as in (D).

When any test, static or dynamic, indicates a deviation from specifications, the trouble is localized by referring to a table in the handbook of the unit, which gives information concerning necessary adjustments or further steps to be taken in locating faulty parts.

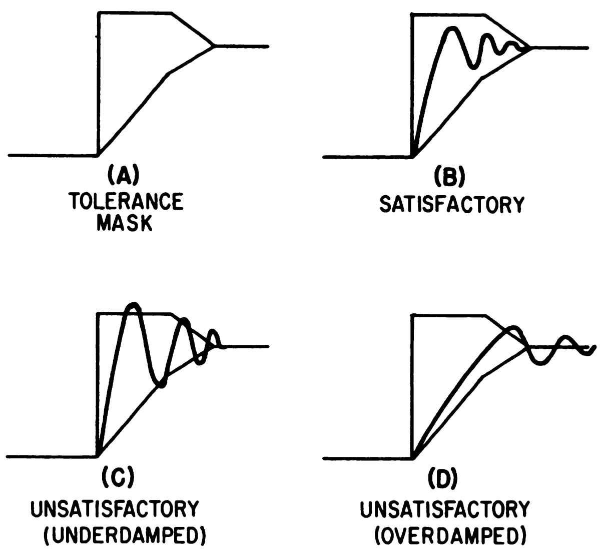


Figure 10-9.—Typical servo responses.

ADJUSTMENTS AND CASUALTY ANALYSIS

The principal types of adjustments made on wing servo units pertain to damping, zeroing of feedback circuits, and balancing of mechanical and electrical components.

Damping Adjustment

Frequently, when dynamic tests reveal improper transient response, the cause is maladjustment within the valve stroker assembly (fig. 10-6). If the indication is excessive overdamping, the adjustable pole pieces are moved toward the armature by equal amounts, thereby increasing the sensitivity of the system. If the response is excessively oscillatory, the

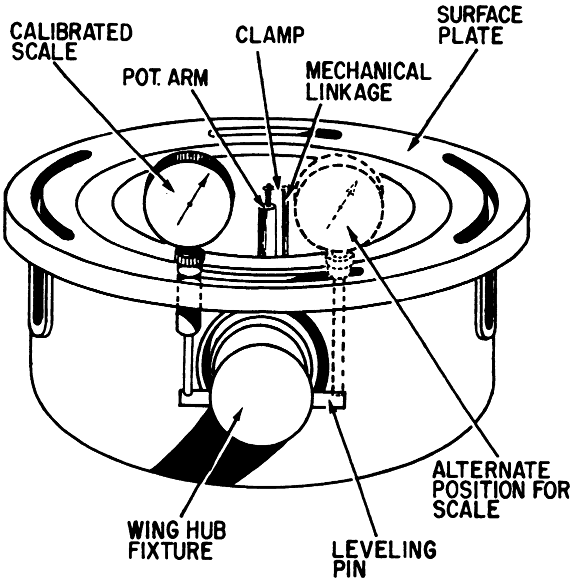


Figure 10-10.—Zeroing the feedback circuit.

condition is remedied by increasing the spacing between the pole pieces and the armature.

Zeroing Adjustment

The procedure of zeroing the feedback circuit in a typical hub section component is illustrated in figure 10-10. The adjustment requires the following equipment: a zeroing plate, wing hub fixtures, a calibrated scale, and an indicating instrument such as a voltmeter.

The zeroing plate is designed to fit with its flat plane parallel to the hub cross section. When the calibrated scale is placed in position (fig. 10-10) it provides a means of measuring the distance between the plate surface and the leveling pin. The latter is carefully adjusted so that the distances between the surface plate and each half of the pin are equal; then a calibrated voltage is applied to the pickoff potentiometer. The arm of the potentiometer, which is mechanically linked to the wing, should be at ground potential electrically when the leveling pin is exactly parallel with the hub cross-sectional axis. If this condition does not exist, the potentiometer must then be adjusted to give zero output. When this adjustment is made accurately, it insures that no false error signal exists due to misalinement of the wing and pickoff. In units containing precision parts and closely machined fittings, extreme care must be exercised to insure proper operation.

Mechanical and Electrical Balance Adjustments

Following the zeroing adjustment, the unit shown in figure 10-6 is then checked and adjusted for mechanical and electrical balance. A mechanical balance check is made with normal hydraulic pressure applied but with no electrical power. When either end of the armature is depressed, the control valve spool is displaced, allowing hydraulic fluid to actuate the piston. When the armature is released, the piston should stop instantaneously rather than drift to a stop. Failure to stop immediately indicates a malfunction, either in the torsion spring or in the valve assembly. If the spring exhibits subnormal tension, the valve position is reset by means of adjusting nuts located on either end of the small wire strut linking the stroker armature to the valve spool (fig. 10-6). The direction of drift indicates whether the valve should be moved in or out before being relocked in position. When the unit is set properly, the wing should move with equal speed in either direction with no overshoot or drift.

After mechanical balance has been insured, the unit (fig. 10-6) is checked electrically, under conditions of normal hydraulic pressure and supply voltage. With full power applied, but with zero error signal, the wing should remain at streamline in order to be acceptable. If this is not the case, lack of electrical balance is indicated which may be due either to difference currents in the control solenoids or to a difference in the solenoid magnetic fields resulting from maladjusted pole pieces.

Difference currents can result from trouble in almost any section of the servo amplifier; the exact cause can be isolated by standard troubleshooting procedures given in the applicable *Handbook of Service Instructions*. When there is imbalance in the fields of the control solenoids, it is usually necessary to reset the pole pieces. This may necessitate the removal of the stroker assembly from the unit and the use of a special fixture, which provides the proper currents to be applied and the means of making the necessary measurements.

Casualty Analysis

As with any electrohydraulic device, missile wing servo units present many possibilities of part failures and malfunctions other than those resulting from maladjustment. After elimination of troubles caused by improper balance,

damping, or zeroing, the majority of servo casualities can be limited to the following major types: inoperative, sluggish action, and inaccurate or unstable response. Troubles of these types can occur either singly or in combination and may be either constant or intermittent.

Complete inoperation of the unit may be caused by electrical power failure; open or short-circuited leads; binding or jammed gears or linkages; or by electronic component failures in tubes, capacitors, resistors, or solenoids. These faults can usually be localized easily and rapidly with the aid of standard test equipment.

More difficult malfunctions resulting in sluggish operation include incorrect gain and phase characteristics, excessive friction, and electronic noise. Analyses of these conditions generally require the use of an oscilloscope, a vacuum-tube voltmeter, and the appropriate schematic diagrams.

Instability and inaccuracy of operation can result from part failures in lead and lag networks, from incorrect phase and gain in amplifiers, faults in feedback circuits, and excessive backlash as well as from drift in the servo valves and electrical imbalance. In the process of isolating troubles in phase-shift networks and in checking amplifiers, it is sometimes necessary to run frequency response tests to determine the exact frequency range in which the malfunction occurs.

QUIZ

1. To compensate for missile servo system time lags, phase lead networks are incorporated. These networks are usually comprised of
   a. resistors and inductors
   b. capacitors and inductors
   c. resistors and capacitors
   d. phantastron circuits

2. Three of the static characteristics of position servos are
   a. discontinuity, dead zone, and minimum motion
   b. dead zone, maximum motion, and continuity
   c. minimum motion, dead zone, and damping
   d. sensitivity, maximum motion, and dead zone

3. Feedback voltage is proportional to
   a. speed of wing response to command signal
   b. position of control valve spool
   c. phase and amplitude of error signal
   d. position of wing shaft

4. One output of the square-wave generator is applied to an amplifier circuit (fig. 10-7) which provides the means for
   a. integrating the output signal
   b. differentiating the output signal
   c. clamping the bottom of the signal at ground potential
   d. introducing a signal response time lag

5. Excessive amplitude and duration of servo oscillation following change in command signal usually causes
   a. saturation of stroker coils
   b. failure of valve stroker struts
   c. discontinuity
   d. sustained hunting

6. The phase of the reference oscillator output (fig. 10-7) is selected to control the
   a. bias on the modulator circuit
   b. direction of wing movement
   c. sweep generator frequency
   d. amplitude of the servo command input

7. Phase lag of the output from the feedback pot is caused primarily by
   a. mechanical friction
   b. mechanical inertia
   c. electrical damping
   d. insufficient input phase lead

8. Dynamic performance of a missile servo system is evaluated with the tester shown in figure 10-7 by applying
   a. a voltage to the feedback potentiometers
   b. small and large amplitude sine wave inputs
   c. small and large amplitude square-wave inputs
   d. a d-c voltage to the scope's "Z" axis

9. A mechanical balance check is made on the missile servo system with
   a. normal hydraulic pressure applied, but with no electrical power
   b. normal hydraulic pressure and electrical power applied
   c. electrical power applied but no hydraulic pressure
   d. no hydraulic or electrical power applied

10. Lack of electrical balance in the missile servo system may be due to difference currents in the
   a. reference oscillator
   b. feedback potentiometers
   c. demodulators
   d. control solenoids

11. Small and large servo transient errors require the use of separate masks on the scope because
   a. the scope sensitivity varies with amplitude
   b. the servo operates on a linear scale
   c. of the nonlinearities of the servo operation
   d. the reference oscillator changes the polarity of deflection

12. In most instances, the normal operating inputs to wing servomechanisms are
   a. high-frequency, low-amplitude
   b. high-frequency, high-amplitude
   c. low-frequency, high-amplitude
   d. low-frequency, low-amplitude

13. The principal requirement of the wing unit is to
   a. minimize the effects of spurious inputs
   b. respond quickly and accurately to applied commands
   c. hold the wings secured
   d. eliminate the effects of spurious inputs

14. A measure of the degree of definition of the output as a function of the input and specified as the maximum variation input with no corresponding change in output is known as
   a. minimum motion
   b. sensitivity
   c. discontinuity
   d. dead zone

15. Settling time is defined as the
   a. duration of significant error following a step change of input
   b. degree of instability in the system
   c. difference in the outputs resulting from the same input
   d. duration of the static output of the servo as a function of input

16. A servo unit is usually adjusted so as to be in a/an______condition.
   a. overdamped
   b. critically damped
   c. slightly underdamped
   d. highly underdamped

17. In the phase-sensitive demodulator, the relative polarities of the d-c outputs are determined by
   a. both phase and amplitude relationship
   b. neither phase nor amplitude relationship
   c. amplitude relationship
   d. phase relationship

18. In reference to figure 10-6, the load impedance of the push-pull power amplifier is
   a. the phase-sensitive demodulator
   b. fixed resistors
   c. valve stroker coils
   d. none of the above

19. In figure 10-6, the wings deflect hard over and a command signal has no noticeable effect. The probable cause of this is a/an
   a. open wiper arm on a feedback potentiometer
   b. broken strut
   c. lack of reference voltage to the demodulator
   d. failure in the phase inverter circuit

20. The factor that determines the time required for the output of a servo unit to reach a new position following a step change of the input is known as
   a. steady-state response
   b. degree of damping
   c. servo response
   d. overall gain

21. Transient analysis of servomechanisms is desirable because
   a. the test equipment is comparatively simple
   b. the tests can be displayed and evaluated with greater ease
   c. the tests generally require less time
   d. of all of the above

22. The static output of a servo as a function of the input is known as
   a. sensitivity
   b. dead zone
   c. minimum motion
   d. discontinuity

CHAPTER 11
TESTING CONTROL INSTRUMENTS

Many different types of devices are required in air-launched missiles to provide guidance information and to aid in steering and stabilizing flight. Among the more important are the devices classified as control instruments, which sense missile motions and develop corresponding electrical signals for the control-system components.

A missile moving freely through space is capable of six separate motions, three of which are rotational and three translational. The rotational movements are angular deviations about the pitch, yaw, and roll axes. The translational movements are straight-line displacements invovling accelerations along the normal, lateral, and longitudinal axes. In general, the instruments employed to sense rotations are gyroscopes; those used for translational motion-sensing are linear accelerometers.

The basic elements of the accelerometer and the gyroscope, their construction, and operating principles are discussed in chapter 8 of *GF 3 & 2*. This chapter continues the discussion and extends it to include control-instrument testing with emphasis on representative test equipment and test procedures.

Gyroscopes and Accelerometers

ATTITUDE AND RATE GYROS

The gyroscope is an essential instrument in the missile field; and without it, achievement of reliable guidance and control would be extremely difficult if not impossible. In air-launched weapons, the major purposes for which gyros are employed are (1) to provide space references, and (2) to provide signals proportional to displacements and rates of pitch, yaw, and/or roll.

Missile gyros are of two fundamental types: attitude (or free) and rate instruments. The basic property of interest in the attitude gyro is rigidity in space by which the rotor axis retains its original orientation regardless of the maneuvering of the missile carrying it. Rate gyros, on the other hand, have one less degree of freedom than attitude gyros, being restrained in one axis. The fundamental property of the rate instrument is its ability to precess, or to change the orientation of the rotor axis in response to rotational input motions.

As applied in missiles, both attitude and rate gyros are parts of complex instrument systems which supply signals to control servomechanisms. In passive homing missiles employing infrared methods of guidance, the attitude gyroscope provides the means by which the seeker element is stabilized, thereby defining a reference line between missile and target. In other systems, notably the beam-rider, attitude gyros establish a reference plane which serves as the basis for developing the guidance intelligence and also provides straight-line course reference for use by the autopilot section of the missile. Rate gyros are employed in missiles of all types. They develop outputs proportional to the velocities of rotation about the principal axes, thereby providing signals used as feedback voltages which assist in preventing overshoot and instability in flight.

ACCELEROMETERS

Accelerometers are essential instruments in most missile control systems. Two types are employed: linear and angular. The former type is designed to produce outputs proportional to straight-line accelerations; the latter is used to sense oscillations and transient rotations about the sensitive axis of the instrument. Both types, when used in missile systems, are equipped with pickoffs which produce electrical outputs that are applied to the control-system components to minimize skids and undesired motions of the vehicle in flight.

The principle of operation of the linear accelerometer involves the measurement of

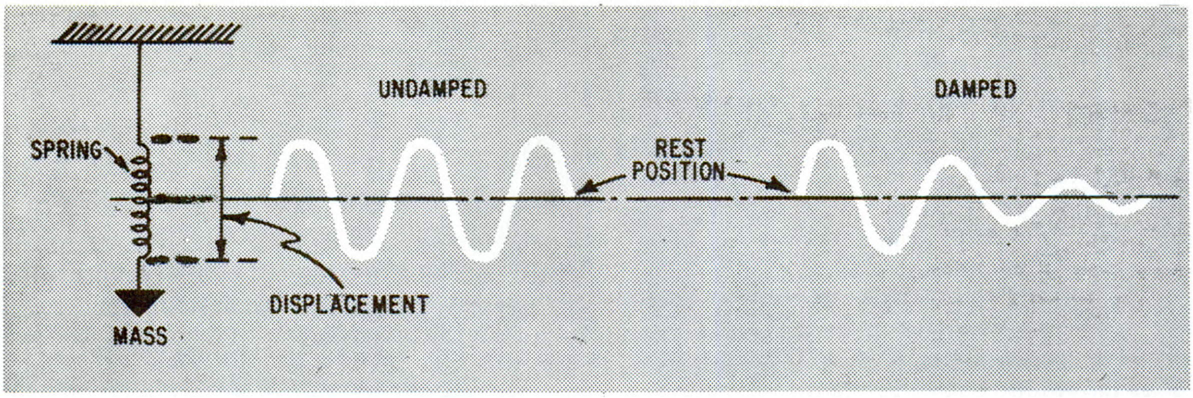


Figure 11-1.—Effect of damping.

the displacement between the instrument case and a spring-mounted mass. The case, which is attached rigidly to the airframe of the missile, is subjected to linear accelerations as the vehicle skids. The mass tends to remain fixed due to its inertia so that a displacement from the normal position occurs which is dependent upon the quantity of acceleration present. A pickoff, such as a potentiometer, converts the displacement to an equivalent electrical output which is then fed to the control system. The latter responds by making the necessary corrective actions to minimize the undesired missile motion.

The principal operational characteristic of the linear accelerometer is the degree of damping present. As shown in figure 11-1, if the mass is displaced and then released, it tends to oscillate about the rest position in what is called simple harmonic motion. If there were no damping action, the mass would oscillate in the manner shown in the drawing on the left. However, because of resistance, the oscillations diminish, as represented in the damped condition illustrated on the right. For efficient operation, it is necessary that the degree of damping be just great enough to give unrestricted displacement, yet offer sufficient restraint to prevent excessive oscillation.

The GF is most apt to encounter linear accelerometers in air-to-air missiles of the homing type in which they are used as stabilizing instruments. Angular accelerometers are integral parts of the guidance section in many missiles of the inertial-guidance class. Because of the excellent reliability of most accelerometers, these instruments are seldom tested as individual components after delivery from the manufacturer.

Gyro Testing

Missile rate and attitude gyros are precision instruments which require the use of relatively elaborate equipment for adequate testing and calibration. The design and production of missile gyro test sets has been one of the many important developments of the missile program. In solving the numerous problems involved, the designers of this type of equipment have achieved many important objectives, one of which is the development of consolidated test sets which are capable of testing gyros of several different missiles and which accommodate instruments that vary widely in size, characteristics, and power requirements. An example of this class of test set is illustrated and discussed in subsequent sections of the chapter. It is desirable first to consider the general procedures employed and the various gyro properties which serve as test criteria.

GENERAL INSPECTION

The initial step in testing a particular gyro is a general visual inspection made without the aid of electronic equipment. This examination serves to detect the more obvious failures such as broken wiring, damaged connectors, loose mechanical parts, burned out windings, and faulty caging mechanisms.

TEST CRITERIA

Following the initial inspection, the gyro is checked by the test set in a series of specific tests selected to determine its operational condition. Among the items which are used as test criteria are motor current, wheel rundown, heater-circuit continuity, damping, limit-stop setting, null, and measurements of outputs derived from pickoff devices.

Motor Current

Measurement of the current drawn by the gyro motor frequently produces evidence of electrical or mechanical abnormalities. If there is more than one electrical phase, each leg should be measured since in polyphase equipment, the currents normally are equal in all phases at any given time. Power or power factor monitoring is not often employed since any malfunctions revealed by these indications are usually shown in current measurements alone.

An additional feature of motor-current measurement is that it gives an adequate indication of wheel speedup. Since the starting torque in a gyro motor is relatively high, the initial, or starting, current is also high. As the gyro wheel rotates at a constantly increasing speed, the current drawn by the motor decreases. Hence, the interval of time required to reach maximum velocity is indicated by the time interval necessary for the motor current to reach a steady minimum value.

Wheel Rundown

In some missiles, gyro power is disconnected at launch and all gyro motion is the result of momentum built up prior to launching while power is still applied to the instruments. Thus, it is necessary to insure that gyros of this type maintain adequate r.p.m. for the period of time equal to that of normal flight. Since small frictional torques have a much greater effect on rundown than on speedup, it is necessary to measure the two separately. This is often done by taking advantage of the fact that a gyro motor becomes a low-power generator when coasting due to its residual magnetism. Thus, the rundown characteristics may be checked by noting whether the output voltage decreases in amplitude by appropriate amounts within a specified time interval following removal of power. The measurement must be made with a high-impedance device to avoid loading down the generator and thus reducing the rundown time. With rate gyros, however, the output from the pickoff device is proportional to wheel speed, and it is preferable to perform the rundown test as part of output performance measurements. This can be done by applying a fixed angular-velocity input to the gyro and observing whether the output decreases by prescribed amounts within a specified time after motor power is removed.

Heater Check

In some missile gyros, damping is accomplished by means of viscous fluids. These instruments are equipped with heaters controlled by thermostats to keep the fluid temperature within proper limits to maintain the correct viscosity. The operation of the heater and thermostat in a gyro of this type can be checked by indicating circuit continuity as a function of time with normal heater voltage applied and under conditions of normal room temperature and heat transmission. This test is usually time consuming and is best performed separately from the remainder of the gyro checks.

Cage-Uncage

This test pertains to attitude gyros only since rate instruments are positioned by restraining springs and are not normally equipped with caging mechanisms. In making the test, the normal caging (or uncaging) signal is applied and the effect is noted either visually or aurally. Further confirmation of the result can be provided by simple continuity checks. Tests to determine whether the caging mechanism brings the gyro to the null position are usually made in another part of the checkout sequence.

Damping

Damping tests are performed only on rate gyros. The output of the gyro is measured in terms of angular deflection about the torque axis in response to an angular-velocity input about the sensitive axis. (The relationship of the axes is shown in figure 11-2.) The optimum response to a sinusoidal input is deflection of a simple harmonic type in which damping prevents the amplitude from becoming excessively large at the natural frequency of oscillation or at frequencies near it.

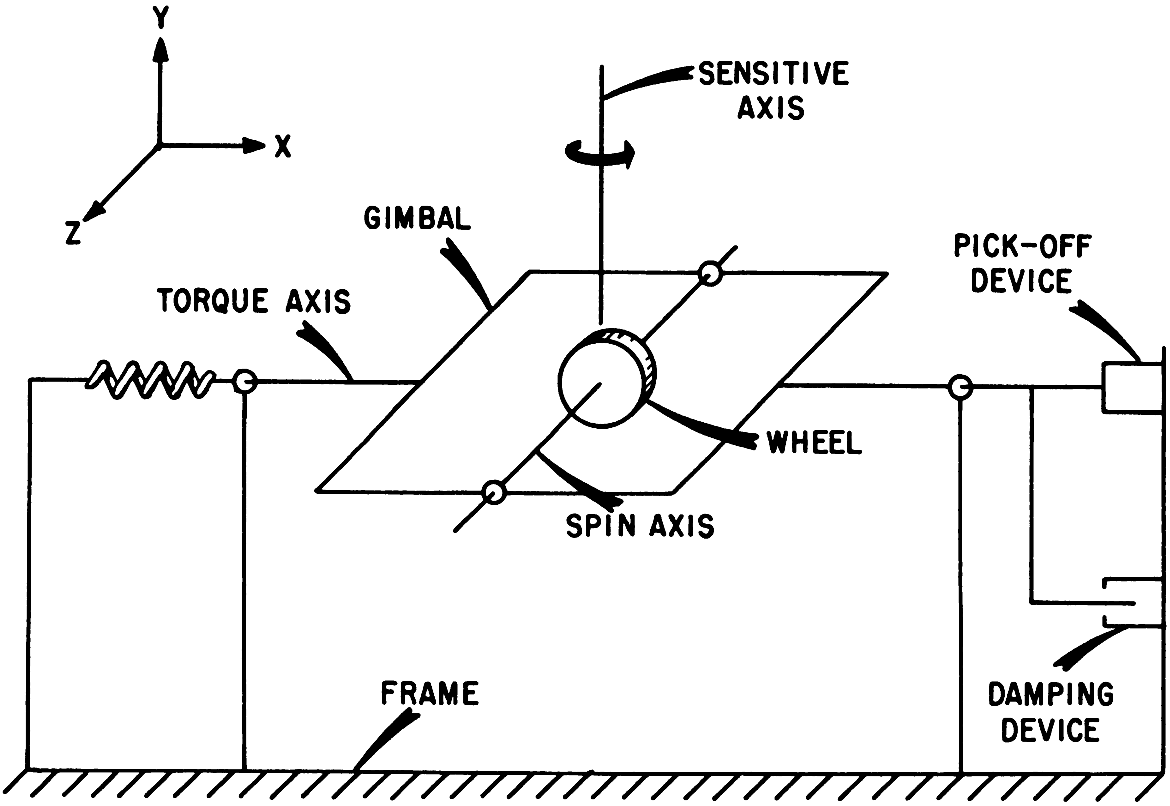


Figure 11-2.—Relationship of rate gyro axes.

A damping test often recommended by gyro manufacturers is made by applying a step-function, angular-velocity input and observing the resulting overshoots or other response characteristics with an oscilloscope. The display is made by triggering the horizontal sweep in synchronism with the leading edge of the step input and by adjusting the sweep duration so that it is long enough to permit the complete damping action to be viewed. For the test to be conclusive, the step-input rise time must be small compared with the natural period of undamped oscillation (usually in the order of 0.01 second). Care should be taken to restrict the step-function amplitude to safe levels, since with large inputs the peak shock torque about the sensitive axis may be large enough to damage the torque springs. There is little danger of damage with the miniature gyros used in many missiles, however, provided the step-function amplitude does not exceed a substantial portion of the gyro's rated maximum input. The amplitude of the step function may be reduced to a small fraction of the rated maximum input without materially decreasing the effectiveness of the test.

Limit Stops

Stop-setting checks, which are of interest principally in rate gyros, are made to insure that the operating range is small enough to limit torsion-wire deflection to safe values. To make this check, the angular-velocity input applied during output testing is raised gradually from normal to greater-than-normal values, and the stop setting is judged by noting the input at which the output stops increasing. An alternative method may be used in which greater-than-normal input is applied first and gradually decreased, thereby revealing the value at which the output begins to fall off.

Output Measurements

In rate-gyro tests, the principal output is read as a function of steady angular velocity about the sensitive axis; with attitude gyros, outputs are read as functions of angular displacements about two sensitive axes (the X and Y axes in figure 11-3). In typical output checks, the pickoff voltage is plotted as the input is applied in a cyclical sequence: from zero to

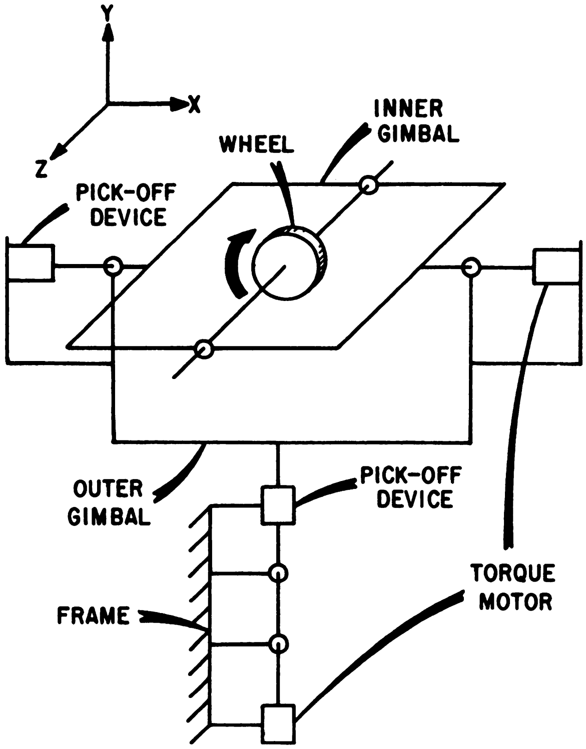


Figure 11-3.—Relationship of attitude-gyro axes.

maximum positive to zero to maximum negative to zero. The resulting curve should fall within a prescribed tolerance range; also, irregularities in the graph show stickiness or backlash if these conditions are present.

In order to detect mechanical defects, it is desirable to introduce angular motions about the nonsensitive axes during output tests. A simple method of doing this is illustrated in figure 11-4, which shows a tilt table to which a rate gyro is attached. (The gyro coordinate axes correspond to those shown in figure 11-2.) With the table rotating at a steady angular velocity, each axis is subjected to a component of the input. Since for all practical purposes the gyro axes are fixed on the table, all components

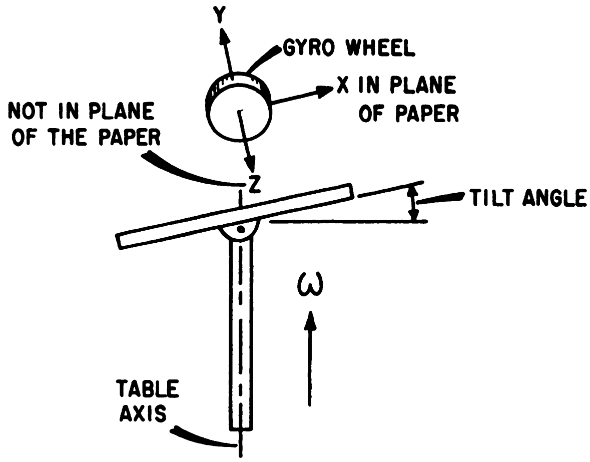


Figure 11-4.—Rate gyro on tilt table.

remain constant; hence any variations in output result from friction or from undesirable torques induced by the rotations about the nonsensitive axes (X and Z).

The table speed, tilt angle, and mounting of gyros (fig. 11-4) may be varied to emphasize or minimize different effects. The following cases are of special importance: (1) With rate gyros, the tilt angle is set at zero and the gyro Y axis is placed parallel with the table axis for rotation about the sensitive axis only; (2) with attitude gyros, the tilt table speed is made zero and the tilt angle and table rotational position are varied to impose desired attitude-change inputs.

If several gyros are contained within a single package, an adaptor may be used to attach the unit to the table in such a manner as to subject all the instruments simultaneously to desired angular-velocity, angular-acceleration, or angular-displacement inputs. The output of one of the instruments is checked with velocity and displacement inputs; and if the readings are found to be within tolerance, the indication is that the orientations of the other instruments in the package are correct.

Gyro Test Equipment

The Gyro Test Set illustrated in figure 11-5 is a general-purpose, precision equipment designed for testing missile gyroscopes under simulated operational conditions. The set, a complete and independent device, has provision for supplying a wide range of mechanical and electrical inputs to the instrument under test and for displaying and analyzing the resulting outputs. By means of special plug-in units it is capable of checking many different gyro characteristics and hence will accommodate many different types of instruments. The functional block diagram (fig. 11-6) indicates the major components of the set—the Power Supply

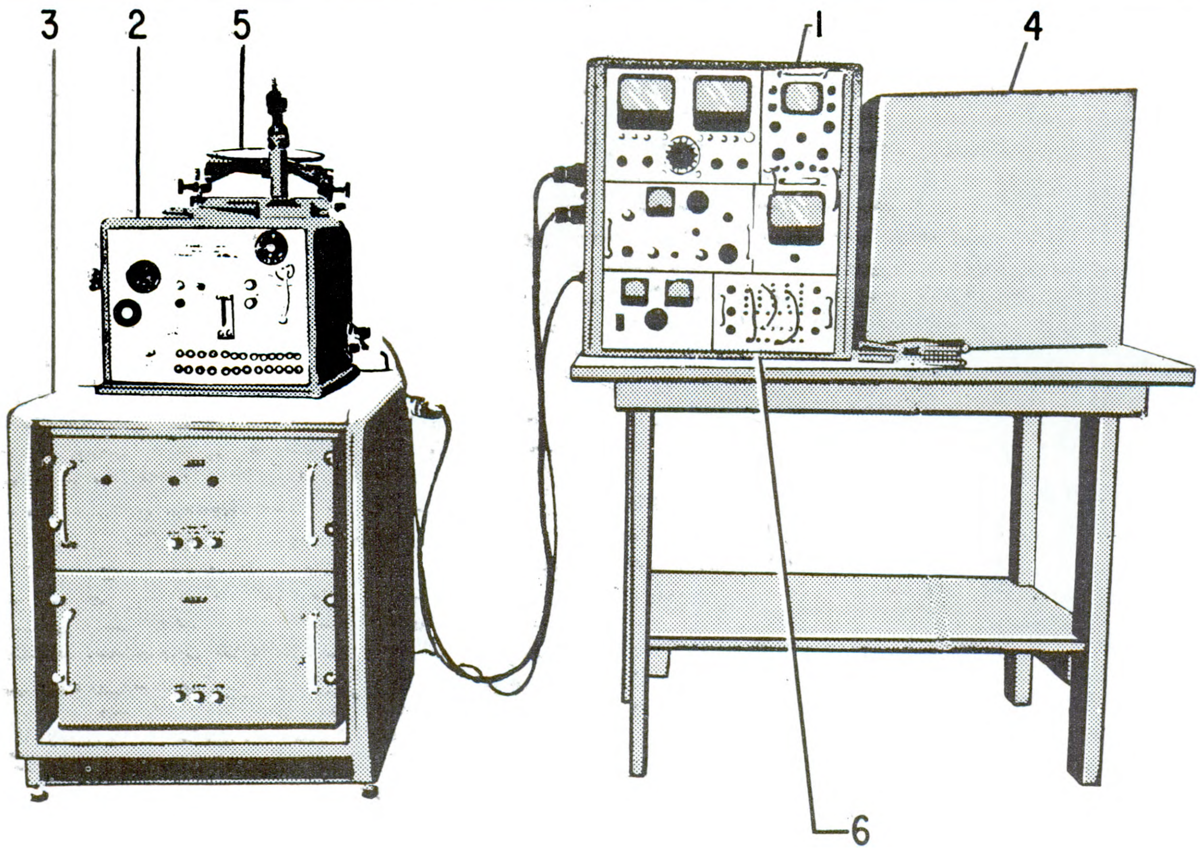


Figure 11-5.—Gyro Test Set.

1. Control-Indicator Group.
2. Gyro Test Set Group.
3. Power Supply Assembly.
4. Electrical Equipment Cabinet.
5. Gyro Tilting Adapter.
6. Control-Indicator.

Assembly, the Control-Indicator Group, and the Gyroscope Test Set Group.

POWER SUPPLY ASSEMBLY

Various voltages are required in the operation of the Gyro Test Set. These are generated by basic equipment operating with inputs of 60-cycle, 115-volt, single-phase power. The Power Supply Assembly provides high-voltage, d-c power for operating all the units in the Control Indicator with the exception of the oscilloscope. It also supplies a-c motor power to the gyro under test.

The d-c outputs of the Power Supply are produced by conventional full-wave rectifiers equipped with electronic voltage regulators. The operation of these circuits is similar to that of the power supplies discussed in chapter 9 of this course. To supply the wide variety of gyro motor voltages required, a special type of electronic oscillator-amplifier is used. This method has several advantages compared with rotating power supplies. The output frequencies and also their phase relationships can be varied with comparative ease; the operator-fatiguing high-level noise produced by most rotating machinery is eliminated; test set vibration is considerably reduced; and the mechanical design of the supply is considerably simplified.

R-C Phase Shifter

The oscillator used to supply motor power is a very stable R-C circuit equipped with a phase shifter. This combination provides either 2-phase or 3-phase outputs as required. For operating 2-phase motors, the device produces 1,000-cycle voltages displaced in phase by 90 degrees; for 3-phase motors it provides either 400-cycle or 800-cycle energy in the

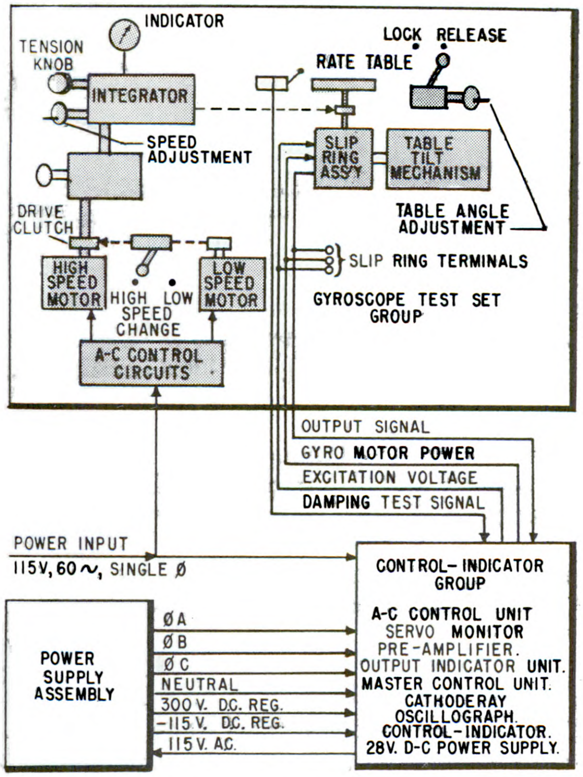


Figure 11-6.—Functional block diagram of Gyro Test Set.

form of three voltages with 120-degree phase displacements. The phase-shifting circuit employed to produce these outputs is shown in figure 11-7. The second section of each of the three tubes consists of a cathode follower which isolates the load from the oscillator and prevents phase pulling. The cathode of each cathode follower is connected in series with a potentiometer to control the output amplitude. Each output phase is then amplified independently by identical circuits.

Operation of Phase-Shifting Circuit

The operation of the phase-shifting device employed in the Power Supply Assembly can be understood by study of the diagrams in figure 11-8. A simplified schematic is shown in (A); (B) represents the equivalent circuit; and (C) shows the vector relationships of the principal voltages involved. In the following discussion, the definitions given in the list below are employed:

R_p is the phase-shift network resistance.

R_i represents equal value plate-circuit and cathode resistors.

C_p is the phase-shift network capacitance.

C_s is the value of stray capacitance in the input to the following stage.

e_o is the output voltage.

e_i is the input voltage.

IR_p is the value of the signal voltage across R_p.

IX_{C_p} is the value of the signal voltage across C_p.

ϕ is the desired value of phase shift in degrees.

To produce the conditions indicated in (C) of figure 11-8, the following relations must be present: R_p must be large compared with R_i (minimum ratio 20:1); C_p must be very large compared with C_s (minimum ratio 25:1); and e_o must be equal to e_i. In figure 11-8(C), the e_i leg of the vector triangle represents the amplitude with respect to ground of the signal voltage at the plate of tube V_1. The e_o leg represents the amplitude of the output, which is displaced by ϕ, the desired phase shift. It is shown by means of the analysis below that the desired phase angle at any given frequency can be produced by appropriate values of R_p and C_p. The equation showing the relation of frequency to the component values can be derived by the following procedure.

Where ϕ is the desired phase shift, and e_o is equal to e_i, $\angle A$ is equal to $\angle B$ (two angles of an isosceles triangle). $\angle C$ is the complementary angle to both $\angle A + \angle B$ and $\angle \phi$, therefore, ϕ is equal to $\angle A + \angle B$ or, $\phi/2$ equals $\angle B$.

Since the tangent of an angle is equal to the side opposite the angle divided by the side adjacent to the angle, then

$$\tan \angle B = \frac{IR_p}{IX_{C_p}}$$

If both numerator and denominator are divided by I,

$$\tan \angle B = \frac{R_p}{X_{C_p}} = \tan \frac{\phi}{2}$$

The value of X_{C_p} is indicated in the formula for capacitive reactance so that

$$X_{C_p} = \frac{1}{2\pi F C_p}$$

thus,

$$\tan \frac{\phi}{2} = \frac{R_p}{\frac{1}{2\pi F\ C_p}} = 2\pi F\ C_p R_p$$

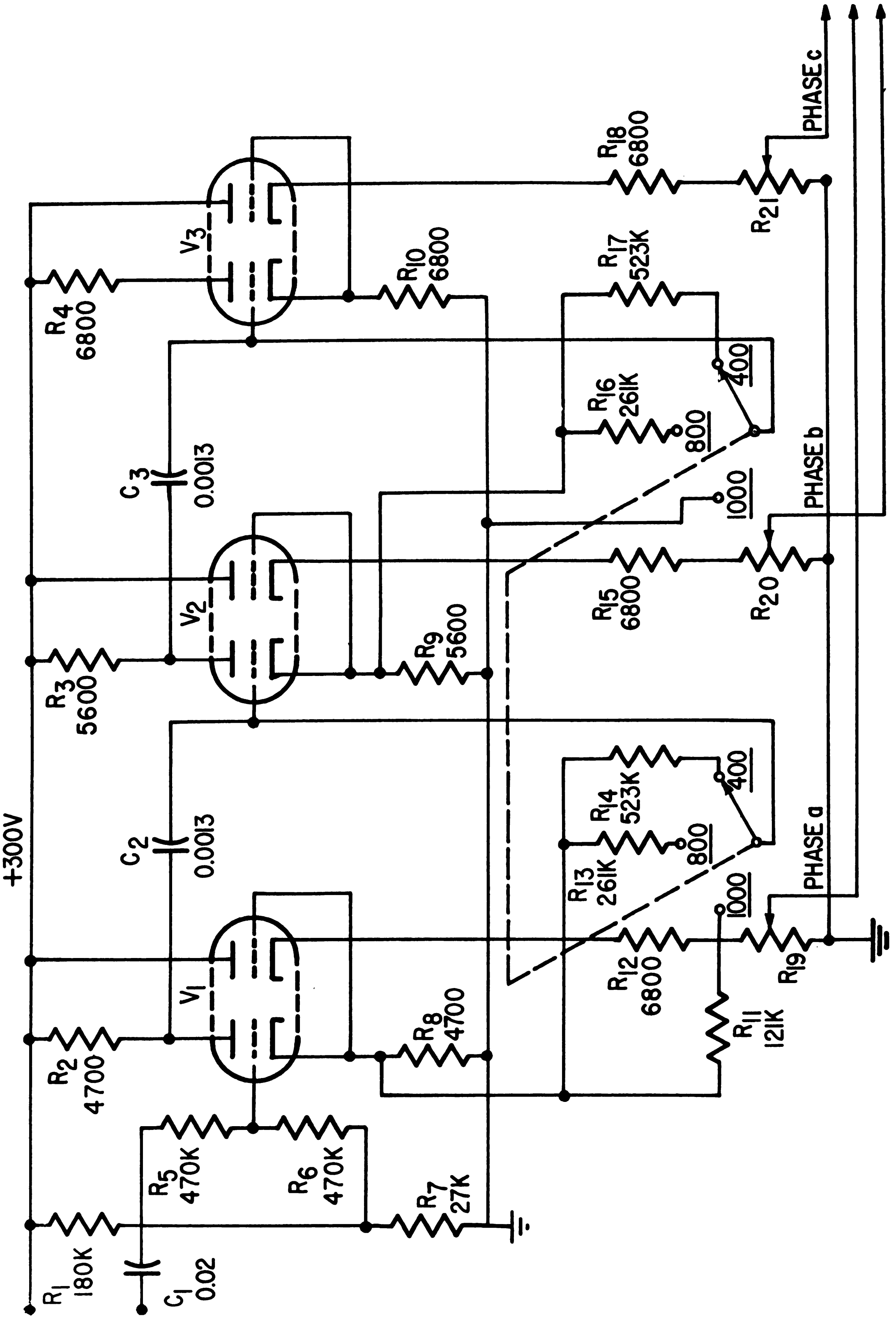


Figure 11-7.—Phase-shifting circuit.

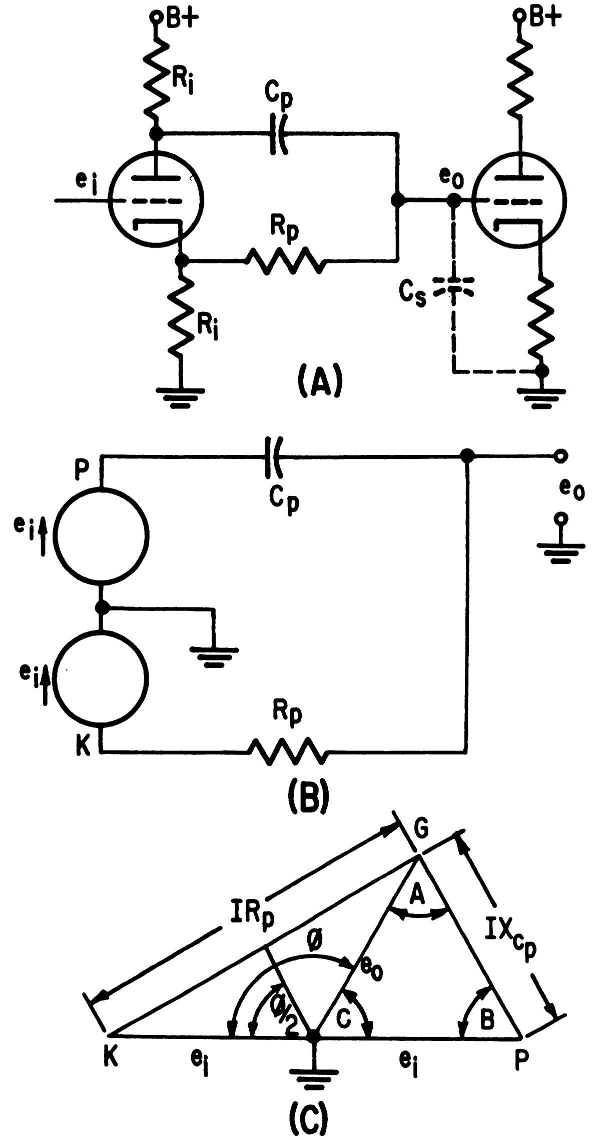


Figure 11-8.—Phase-shifter operation: (A) typical schematic diagram; (B) equivalent circuit; (C) vector diagram.

Solving for F,

$$F = \frac{\tan \phi/2}{2\pi C_p R_p}$$

Applying this in a 3-phase circuit where ϕ is 120 degrees, $\tan \phi/2$ is equal to tan 60 degrees ($\sqrt{3}$):

$$F = \frac{\sqrt{3}}{2\pi C_p R_p}$$

and in a 2-phase oscillator where ϕ is 90 degrees, $\tan \phi/2$ is equal to the tangent of 45 degrees which is 1:

$$F = \frac{1}{2\pi C_p R_p}$$

THE CONTROL-INDICATOR GROUP

The Control-Indicator Group contains the electronic circuitry required for control and for making the various measurements and displays of output data. As indicated in figure 11-9, this section of the test set contains the following major units:

1. Master Control Unit.
2. A-C Control Unit.
3. The 28-volt, D-C Power Supply.
4. The Servo Monitor Amplifier.
5. Output Indicator Unit and Cathode-Ray Oscilloscope.

The Master Control Unit controls the application of primary power to all units of this group and also to the Power Supply Assembly. In addition, it provides the means for controlling the gyro motor power supplied to the Gyroscope Test Set Group. A variable voltage transformer supplies the voltage for the 28-volt, d-c circuit, thereby permitting the output of the latter to be varied from 0 to 35 volts. The Master Control Unit also contains a d-c voltmeter and d-c milliammeter for indicating the output d-c voltage and that portion of the current delivered to gyro motors from the 28-volt supply.

The 28-volt, D-C Supply produces all the low-voltage energy needed to meet the requirements of components such as solenoids, heaters, and certain gyro motors. The A-C Control Unit governs and indicates the quantities of 2-phase or 3-phase voltage and current supplied to gyro motors operating on a-c power.

The Servo Monitor Preamplifier amplifies the gyro pickoff output signal, compares the output signal with the input signal with respect to phase, and rectifies the amplified signal. The resulting d-c voltage, which is connected to the Output Indicator, is positive when the pickoff output is in phase with the reference (pickoff input) signal and negative when the two differ in phase by 180 degrees.

The Output Indicator Unit measures the amplitude of the gyro error signal and indicates whether this signal is in phase or 180 degrees out of phase with the reference signal.

In order to make the equipment shown in figure 11-5 a universal gyro test set, several Control-Indicator Units of the plug-in type are supplied for use with it. Each of these units is specially designed for a particular group of missile gyros and contains only those circuits

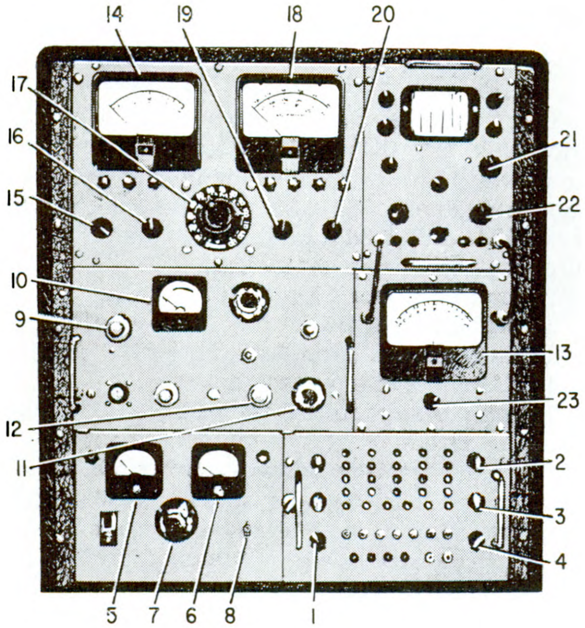


Figure 11-9.—Control-Indicator Group.

1. Reference signal Switch.
2. Gyro motor power frequency switcn.
3. Reference oscillator level control.
4. Reference oscillator frequency switch.
5. D-C Voltmeter.
6. Gyro motor current meter.
7. 28-volt d-c supply control.
8. Gyro motor power switch.
9. Reference voltage control.
10. Reference voltage meter.
11. Use-off-cal switch.
12. Position Control.
13. Output Indicator meter.
14. A-C voltmeter.
15. Range switch.
16. Phase switch.
17. Line voltage control.
18. A-C milliammeter.
19. Range switch.
20. Phase switch.
21. Sync source switch and amplitude control.
22. Sweep time/major division switch and vernier control.
23. Signal voltage switch.

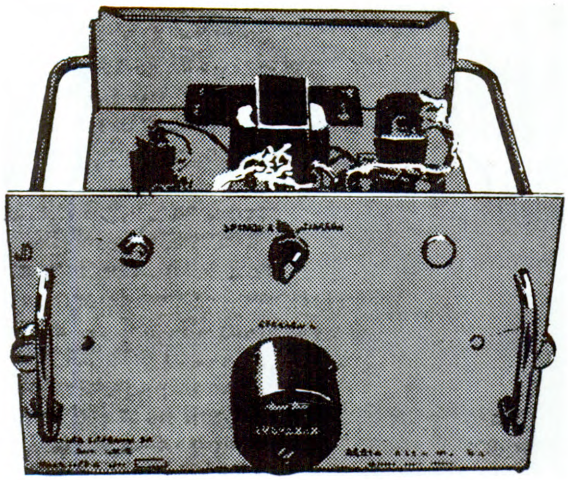


Figure 11-10.—Plug-in control unit.

and controls which directly relate to instruments of that group. The unit illustrated in figure 11-10, for example, is used in testing the rate gyroscopes of a typical semiactive homing missile.

THE GYROSCOPE TEST SET GROUP

This group, illustrated in figure 11-11, is comprised of the mechanical and electrical components necessary for producing variable rotational speeds of the test-set turntable and for adjusting the angle at which the table is inclined. Normally, the gyro to be tested is mounted on the table and subjected to rotational speeds ranging in value from approximately 0.05 to 100 degrees per second at angles ranging from 0 to 90 degrees with respect to the horizontal.

The turntable is driven by either of two constant-speed electric motors, one for high and one for low speeds. The high-speed motor operates a main drive shaft and rotates a rubber surfaced idler wheel through a friction wheel. As shown in figure 11-12, the idler wheel drives the input disc of the variable-speed transmission, called the integrator. A speed change lever serves as a control for introducing either motor as the driving device.

The integrator (fig. 11-12) contains two parallel steel discs approximately 4-1/2 inches in diameter. These are separated by two steel drive balls with 1/2-inch diameters which transmit rotation from the input disc to the output disc. The former disc rotates at constant speed on either high or low range; the speed of the output disc can be varied by adjusting the distance between the disc axes and the drive balls. Thus, to increase the output speed, the axis of the drive balls must be moved toward the outer edge of the input disc. A precision leadscrew and a dial indicator provide the means for adjusting and measuring the speed of the output disc.

Test Procedures

Gyroscopes are used for many purposes and are built with widely different capabilities and in many shapes and sizes; hence it is not possible to list a series of tests which apply to all instruments. In the following discussion, the intent is to give examples of the tests performed on typical rate and attitude gyros and to exhibit the general principles involved. The procedures described are used with the test set illustrated in figure 11-5. References are made when necessary to various meters, switches, and controls, which are located on the panel of the Control Indicator shown in figure 11-9.

The test set used for the checks discussed here is a universal device which provides a wide range of motor voltages and auxiliary voltages. Incorrect adjustments of these potentials could result in severe damage to the gyro under test and, hence, extreme caution must be taken to insure that all controls and switches are set in the proper position before power is applied.

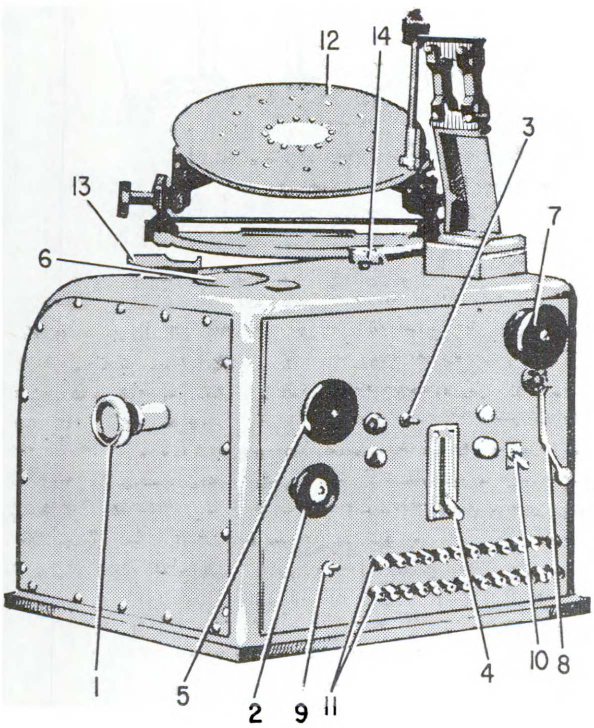


Figure 11-11.—Gyroscope Test Set Group; operating controls.

1. Tension knob.
2. Drive clutch handwheel.
3. Power switch.
4. Speed change lever.
5. Speed adjustment handwheel.
6. Dial indicator.
7. Table angle adjustment handwheel.
8. Lock-release lever.
9. Damping test switch.
10. Main power switch.
11. Slipring terminals.
12. Gyro Tilting Adapter.
13. Table stopping mechanism.
14. Stop pin.

STARTING CURRENT AND RUN-UP TEST

This test employs the motor-current criterion discussed previously. The gyro under test is checked to insure that the time required for it to reach rated speed is within the specified value and also to insure that the current drawn does not exceed a certain maximum value. The A-C CONTROL unit of the test set contains a current range switch which is set at maximum range and a PHASE SWITCH which is placed in the position required for measuring the current in phase A. Simultaneously with the application of power, the operator sets a stopwatch in motion. He observes the current drawn on the GYRO MOTOR CURRENT meter and then rotates the PHASE SWITCH through the various positions necessary for reading current in each phase. The values indicated are of starting current and the reading must be taken within the first five seconds after applying motor power. The range of the current indicator may be reduced if the needle deflection is small on maximum range. When the motor current reaches a steady value, the elapsed time is noted as indicated by the stopwatch. This interval is the runup time. To be acceptable, the starting current, running current, and runup time must be within tolerance limits given in the specifications of the instrument.

TESTING RATE GYROSCOPES

In tests of starting current and runup time, the procedures are similar for both rate and attitude gyroscopes. In other tests performed by the set shown in figure 11-5, the procedures differ somewhat for the two classes of instruments. The principal tests made on rate gyros include null; threshold sensitivity; linearity,

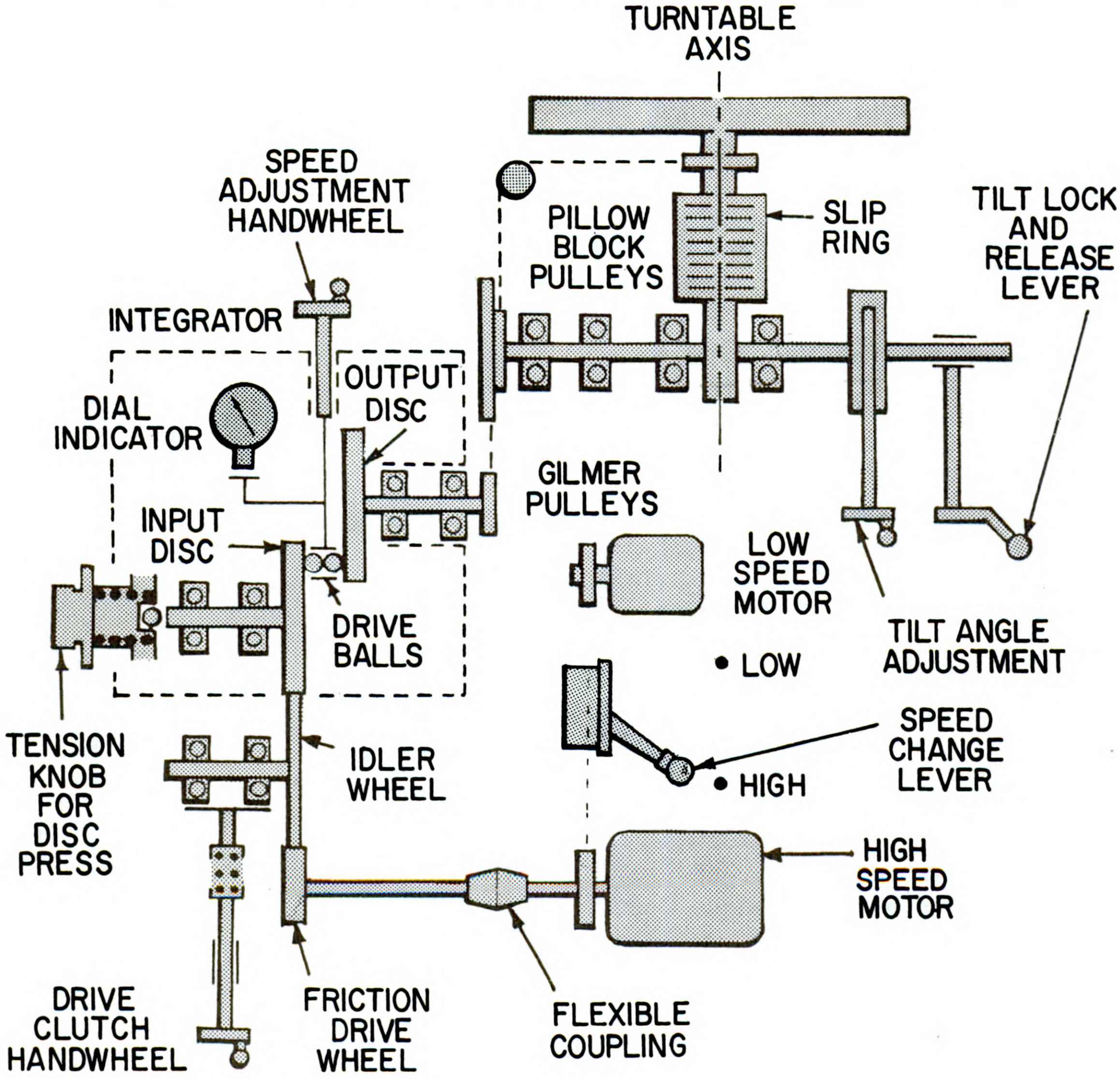


Figure 11-12.—Gyroscope Test Set Group: block diagram.

sensitivity, calibration and stop setting; cross-axis sensitivity; and damping checks.

Null Tests

With most rate gyros, specifications require that in the static condition the outputs produced by the pickoff equal zero or else differ from zero by less than specified amounts (± 5.0 millivolts are typical tolerance limits). The Output Indicator Unit of the test set contains a SIGNAL VOLTAGE switch which selects either the normal (in-phase) voltage or the quadrature (out-of-phase) voltage of the gyro under test. With the instrument at rest, these voltages are measured by means of a meter contained in the test unit to determine whether they fall within the required tolerance values.

Threshold Sensitivity

This quantity is measured by determining the minimum amount of angular motion input necessary to produce an output reading other than the null value. The gyro is placed on the turntable of the test set and rotated at a low rate of angular velocity (in the order of 0.08 degree per second). The pickoff output is noted

when the table starts to rotate. If there is no observable change in output, the speed of the table is increased until a definite increase is noted. The process is then repeated with the turntable rotating in the opposite direction with the change in output occurring in opposite phase. The rotational speeds required to produce corresponding output changes are then compared with standard figures given in the handbook.

Linearity, Sensitivity, Calibration, and Stop Setting

These four characteristics are checked by first setting the turntable in rotation at a low speed in the clockwise direction. The output of the instrument is recorded. The speed of the table is increased in steps and readings are made at five different values of angular velocity. These readings are then compared with prescribed standards to give indications of linearity, sensitivity, and calibration of the instrument. A further increase in the rotational speed is made to bring the gyro to the point where additional torque results in no increase in output. In this condition, the movable element of the pickoff has reached the stop; the corresponding value of turntable speed and the output voltage of the gyro are recorded and compared with standard values.

The speed of the turntable is next decreased in steps and readings are taken at the same speeds as in the previous series. These values should be approximately the same as in the initial set of readings. The test is completed by performing the same process with the turntable rotating in the counterclockwise direction.

In most cases, the normal or in-phase component of voltage is employed; however, the authorized procedures for some instruments require that a phase-shift measurement be made. In this case, two readings are taken at each speed: the normal and the quadrature voltages. The phase shift is then determined by the formula

$$\text{Phase shift} = \text{Arc tangent } \frac{\text{Quadrature output}}{\text{Normal output}}$$

in which the symbol Arc tangent signifies the angle in degrees whose tangent is equal to the value of the fraction. If the specifications make no requirement with regard to phase shift, however, then in-phase readings only are made.

Cross-Axis Sensitivity

The gyro mounting employed with the test set provides the means for placing rate gyros in any of the following orientations:

1. Sensitive axis parallel with the turntable axis.
2. Precession axis parallel with the turntable axis.
3. Spin axis parallel with the turntable axis.

To test cross-axis sensitivity, the gyro is mounted first in position 2 and then in position 3. In each position, the turntable is rotated at maximum rated speed for the particular gyro, and the pickoff voltage is observed on the voltmeter in the Output Indicator Unit. Normally, operating gyros are insensitive to rotation about either the spin or the precession axis and in both positions the meter should read approximately zero.

RATIO $\frac{(b)}{(a)}$	DAMPING RATIO
0.02	0.8
0.05	0.7
0.09	0.6
0.17	0.5
0.26	0.4
0.37	0.3
0.52	0.2
0.73	0.1

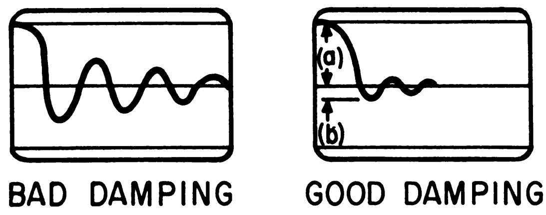


Figure 11-13.—Oscilloscope indications in damping tests.

Damping Tests

The turntable contains a stopping mechanism which operates in conjunction with an optionally installed stop pin. The DAMPING TEST switch is placed in the ON position and the table is rotated in a clockwise direction at a rotational rate equal to approximately 50 percent of the maximum rated value. Then with power on, the output voltage of the pickoff is observed.

Next, the SYNC, SYNC AMPLITUDE, and ATTENUATION controls of the oscilloscope unit are set in proper positions as prescribed in the operating instructions. When the stop pin on the rotating table passes the stopping mechanism, the latter is moved into position to engage the pin on the next time around. Upon engagement, the oscilloscope sweep is triggered and the turntable is brought to a sudden stop. This action imparts a negative step-function input to the gyro, the output of which is impressed on the oscilloscope. The result is a sweep pattern of the type shown in figure 11-13. Calculation of the damping ratio is made by use of the ratio b/a indicated in the figure. Examples of good and bad damping are shown as well as the significance of the b factor (first overshoot) and the a factor (the original amplitude).

TESTING ATTITUDE GYROS

The following tests are performed with the test set during checkout of attitude gyros:

1. Sensitivity and calibration.
2. Null.
3. Scorsby motion tests: drift due to bearing friction.
4. Random drift and drift due to unbalance.

Sensitivity and Calibration

Attitude gyroscopes have three sensitive axes. These, as indicated in figure 11-4, are the outer gimbal, the inner gimbal, and the spin axes. The two gimbal axes are mutually perpendicular and in the caged (or zero reference) position, the spin axis is perpendicular to the outer gimbal axis. The drawing shows a typical attitude gyro with the spin axis mounted vertically on the gyro test-set turntable. Gyros with vertical spin axes are sensitive to pitch or yaw, and roll motions of the airframe to which attached, while gyros with horizontal spin-axis orientation are sensitive to motions of pitch and yaw in the airframe. For purposes of checking sensitivity, the gyro is mounted in the test equipment in the same orientation as in the airframe (subject to exceptions noted in certain gyro specifications).

To check the sensitivity and calibration of the vertical spin gyro, the unit is first mounted in the proper adaptor bracket as in figure 11-14. The turntable is rotated by hand so that the outer gimbal axis is parallel to the turntable tilt axis. With the gyro uncaged and running, and with the turntable horizontal (no tilt), the outer gimbal pickoff voltage is read on

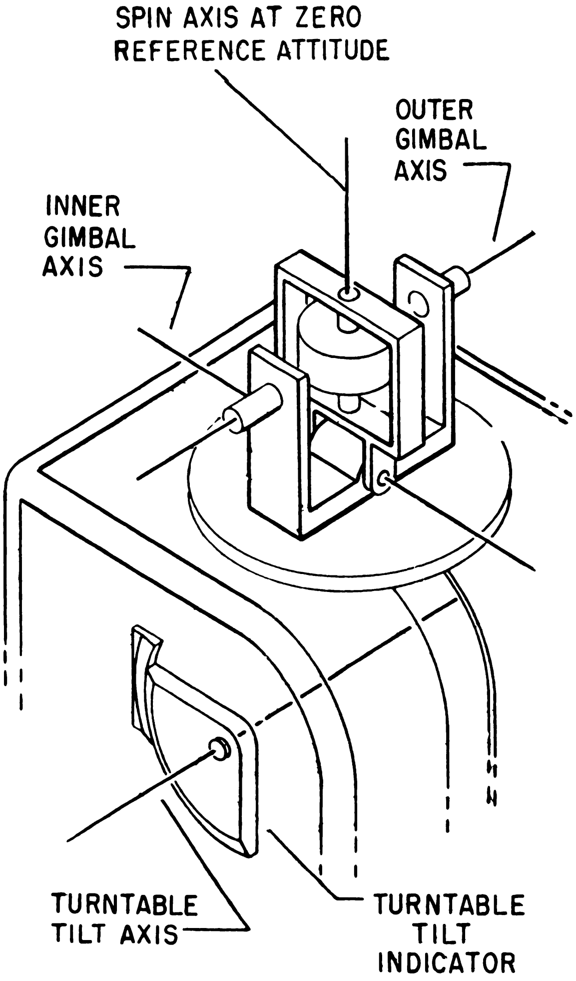


Figure 11-14.—Typical vertical spin-axis gyroscope mounted on turntable.

the Output Indicator Unit meter and recorded. The table is then tilted in progressive steps to the maximum rating of the gyro. Each time the table is tilted to a new position, it is necessary to make sure that it is not rotated prior to taking a reading. For a linear calibration of a gyro, the output must change equally for equal changes in degree of tilt. Sensitivity is determined by the amplitude of the output for specified tilt inputs. Sensitivity and calibration in the opposite sense may be checked by rotating the table 180 degrees and following a similar procedure.

Scorsby Motion Test: Drift Due to Bearing Friction

Tests of this type require the use of a Gyro Mounting Adaptor (shown in figure 11-12 which

transforms the normal turntable rotation into Scorsby motion in which a nodding component is added. With the tilt angle set to zero, the table is rotated at a rate corresponding to the Scorsby motion cycling rate required by the gyro specifications. Then, with the gyro uncaged, a reading is taken on the pickoff devices. The theoretically ideal output is zero, assuming that there is no friction or no unbalance and that the pickoff devices are exactly centered.

The tilt angle of the mounting adaptor is then set to the maximum deviation angle as given in the gyro specifications. The table is allowed to rotate clockwise for one minute after which the direction of rotation is reversed at one-minute intervals for whatever total time is required. This action imparts the necessary Scorsby motion in each direction. After the time requirement is met, the operator turns the power off and resets the turntable to the original position with zero tilt. The pickoff outputs from both gimbals are then compared with those taken before the test was started.

Random Drift and Drift Due to Unbalance

Drift tests are initiated by orienting the caged gyro on the turntable so that the inner gimbal axis is vertical. (In this position, unbalance of the inner gimbal should have negligible effect. Any unbalance of the outer gimbal will cause a torque on the outer gimbal which will precess the inner gimbal. The drift of the outer gimbal is due to random effects.)

The gyro is then uncaged and readings are taken from both pickoffs as soon as possible. After a reasonable interval (one to five minutes), the pickoff voltages are read again and compared with the original readings. Excessive drift due to unbalance will be indicated by a larger-than-normal difference between the two sets of readings.

The gyro is then recaged and oriented on the turntable so that the outer gimbal is vertical. (Any unbalance of the inner gimbal will cause a torque on the inner gimbal which will precess the outer gimbal. The drift of the inner gimbal will be due to random effects.) Two sets of readings are again taken and compared as in the preceding portion of the test.

Other Tests

Other tests may be required which include checks for correct operation and positioning rates of torque motors and the proper functioning of various auxiliary devices. When testing instruments with unusual or unfamiliar construction, the appropriate maintenance manual must be consulted to insure that all authorized checks have been performed and correct procedures followed.

QUIZ

1. A missile moving freely through space is capable of______ separate motions
   a. 6
   b. 3
   c. 4
   d. 5

2. An instrument used to sense translational motion is a
   a. rate gyro
   b. amount gyro
   c. attitude gyro
   d. linear accelerometer

3. Rate gyros develop outputs proportional to
   a. their velocity of rotation about the sensitive axis
   b. their velocity of rotation about the gyro spin axis
   c. their velocity of rotation along the longitudinal axis of the missile
   d. the velocity of the missile in flight.

4. The instrument which senses transient rotation about the sensitive axis of that instrument is a/an
   a. free accelerometer
   b. lateral pickoff
   c. angular accelerometer
   d. linear accelerometer

5. The principal operational characteristic of the linear accelerometer is
   a. its ease of maintenance
   b. the degree of damping present
   c. its rigidity in space
   d. the extra speed available

6. In accelerometers, damping is used to
   a. prevent oscillation of the accelerometer
   b. regulate the speed of the rotor
   c. limit the output of the pickoff
   d. cause the missile to over-correct

7. The initial step in testing missile gyros is a
   a. sensitivity check
   b. null check
   c. motor current check
   d. visual inspection

8. Gyro motor current will be minimum when the gyro has
   a. reached its maximum speed
   b. just started
   c. a shorted winding
   d. reached half speed

9. On missile gyros which employ polyphase motors, current should be measured in
   a. two windings only
   b. transformer primary
   c. all windings
   d. one winding only

10. The wheel rundown check of missile gyros
   a. will always be made on missile gyros
   b. will affect rotor speed more than gyro precession
   c. is used to check for small frictions
   d. is not necessary because the gyros are precession instruments

11. The free gyro rundown check is often performed by
   a. using the gyro as a generator and measuring the output
   b. measuring the time that it takes the gyro to run down
   c. checking the amount of precession for a given length of time
   d. using a low-impedance measuring device to match the impedance of the motor

12. The rate gyro rundown test is normally performed
   a. by leveling the rate gyro and with no motion observing its output
   b. in the same manner as that for a free gyro
   c. with gimbal restraint removed
   d. by applying an initial fixed angular-velocity input and observing output changes

13. From attitude gyros, the output is read as a function of angular displacement about
   a. the spin axis
   b. two sensitive axes
   c. one sensitive axis
   d. three sensitive axes

14. Referring to figure 11-3, the sensitive axes of the gyro are the________axes.
   a. X and Z
   b. Y and Z
   c. X, Y, and Z
   d. X and Y

15. In the sensitivity test for attitude gyros, the tilt table speed is
   a. kept at a steady high rate
   b. varied
   c. made zero
   d. kept at a steady low rate

16. (Refer to fig. 11-7.) The purpose of R_{19}, R_{20}, and R_{21} is to
   a. balance the conduction of their respective tubes
   b. adjust the amplitude of each phase of output voltage
   c. adjust the frequency of the output
   d. adjust the phase relationship of the three outputs

17. (Refer to fig. 11-8.) The minimum ratio of R_p to R_i must be
   a. 20:1
   b. 25:1
   c. 25:2
   d. 20:25

18. (Refer to fig. 11-8.) In the relationship of C_p to C_s the minimum ratio must be
   a. 1:25
   b. 1:20
   c. 25:1
   d. 20:25

19. (Refer to fig. 11-11.) The turntable subjects the gyro to rotational speeds ranging from
   a. 0 to 90 degrees/sec at angles from 0.05 to 100 degrees from the horizontal
   b. 0 to 100 degrees/sec at angles from 0.05 to 90 degrees from the horizontal
   c. 90 to 100 degrees/sec at angles from 0.05 to 100 degrees from the horizontal
   d. 0.05 to 100 degrees/sec at angles from 0 to 90 degrees from the horizontal

20. In figure 11-11, the table is driven by __________ speed motor(s)
   a. one variable
   b. one constant
   c. two variables
   d. two constants

21. The speed of the integrator (fig. 11-12) is increased by moving the
   a. drive balls towards the axes of the discs
   b. discs away from one another
   c. drive balls toward the outer edge of the disc
   d. input discs toward one another

22. In testing gyros, finding the minimum angular input necessary to produce an output is known as the_______test.
    a. threshold sensitivity
    b. null
    c. linearity
    d. damping

23. In testing attitude gyros, the Scorsby motion test will check
    a. drift due to bearing friction
    b. rotor rotational speed
    c. unbalance of the gyro motor
    d. all of the above

24. Gyros with vertical spin axes are sensitive to
    a. yaw and roll motion only
    b. pitch or yaw, and roll motion
    c. pitch and yaw motion only
    d. pitch and roll motion only

CHAPTER 12

PUBLICATIONS, RECORDS, AND REPORTS

As senior enlisted technicians, GF1's and GFC's have greater responsibilities than lower rated personnel in the duties of installing, adjusting, maintaining, and testing missile equipment, both electronic and nonelectronic. In these duties, the GF is required to have ready answers for the many questions that arise concerning his equipment. Because of the variety of equipment with which he is associated, it may not always be possible for the man in charge to have all the answers. However, it is essential that he know where to find the required information needed to take corrective measures or to direct the work of his subordinates.

There are many types of publications available which help the GF in the performance of his professional duties. Examples of these, as well as the principal types of records and reports associated with air-launched missiles, are described in the following pages.

The Technical Library

In order that a complete set of needed publications may be procured, properly filed, kept current, and made available to interested personnel, the Guided Missile Division in each activity should establish and maintain a technical library. The importance of this is evidenced by the fact that the library receives a grade in annual inspections.

The technical library should contain all letter publications and technical manuals that are available for the equipments installed in the missile shop or serviced by missile personnel. In addition, the library should contain material of general informative nature such as Electronic Digests and also publications useful for training purposes. The technical library should be kept in an orderly manner and its facilities made available to all personnel needing them. Where many people utilize the library, it is imperative that a checkout system be instituted for essential publications so that interested personnel may locate them when they are needed.

Among the publications and papers which may be contained in the library, those of major importance to the missileman are given in the following list. These items either assist in procuring newly published technical information or else facilitate maintenance and repair of equipment.

1. The *Naval Aeronautic Publications Index*.
2. Technical Publications:

    a. Handbooks of Service Instructions and Illustrated Parts Breakdowns.

    b. Electronic Material Bulletins and Electronic Material Changes.

    c. Appropriate bureau Instructions and Notices.

    d. NAESU *Digest of U.S. Naval Aviation Electronics*.

    e. Allowance Lists.

The remaining part of this section is devoted to discussion of the types of information provided by these publications, its value for the missileman; and in some cases, the methods recommended for using the material included.

THE NAVAL AERONAUTIC PUBLICATIONS INDEX

This set of publications is issued by authority of the Chief, Bureau of Aeronautics, and consists of lists of publications originated by the following sources:

1. Chief of Naval Operations.
2. Deputy, Chief of Naval Operations for Air.
3. Bureau of Aeronautics.
4. Aviation Supply Office.
5. Bureau of Ordnance.

The *Naval Aeronautic Publications Index* is made up of three parts: The Numerical Sequence List, Part I, NavAer 00-500; the

Equipment Applicability List, Part II, NavAer 00-500A; and the Aircraft Application List, Part III, NavAer 00-500B.

Numerical Sequence List, NavAer 00-500

Part I of the Index is a complete listing by assigned code number and title of all available naval aeronautic publications distributed by the Bureau of Aeronautics, and stocked for issue as of the date of publication. It is subdivided into groups according to type of aircraft, equipment, or units thereof. A complete breakdown of the subject groups is given in the table of contents following the title page.

The listed publications are unclassified unless otherwise indicated in the column headed Security Class. Security classifications are kept current in accordance with information released by the BuAer Security Office and the Index reflects the latest information available.

Equipment Applicability List, NavAer 00-500A

Part II of the Index is used for determining or locating the manuals and similar publications available for a particular aircraft, component, or other equipment. All equipments are listed in alphabetical-numerical order and all publications pertaining to the subject involved are listed by assigned number. Instructions for ordering these publications are given in Part I of the Index.

The structure of the guided missile places it in the same category as aircraft. Hence, it is listed in Part II in group 01, Airframes, under the subdivision headed, Guided Missiles.

Aircraft Applicability List, NavAer 00-500B

The third part of the Index lists technical manuals applicable to particular aircraft and related equipment. The entries are classified according to aircraft model numbers.

TECHNICAL PUBLICATIONS

Technical publications of importance to the missileman include equipment manuals, pamphlets, and magazines. These supply much of the information needed in maintaining and repairing missile equipment, in keeping informed concerning new equipment, and in training personnel of lower rates.

Handbooks of Service Instructions

These manuals are the primary sources of authoritative information on specific equipments. They give instructions for preparing the gear for use, explain the theory of operation, and present detailed procedures to be employed in maintenance. In most missile and test-set handbooks, the material is divided into seven sections, each of which covers a major subject area.

Section I. Description and Leading Particulars. The first section usually gives a description of the equipment and the general principles of its operation. It also includes information on the interchangeability of units and gives electrical, mechanical, and physical characteristics of the set and its various components.

Section II. Special Test Equipment and Special Tools. This section lists and illustrates all special equipment and tools needed for handling and testing, and gives instructions for their use. It also contains directions for modifying test equipment for special purposes when necessary. For example, if it were necessary to fabricate special test harness for a particular check, the directions would be included in this part of the handbook.

Section III. Preparation for Use and Reshipment. This portion prescribes the methods to be used in handling the equipment from the time it is received until it is ready for use. It contains specified instructions on topics such as uncrating, assembling, removal from operation, and recrating for reshipment, and covers items such as the interconnections of cables, checks required, and adjustments to be made during installation.

Section IV. Theory of Operation. A general description of the particular system is presented first. This is followed by detailed analyses of individual circuits.

Section V. Organizational and Operational Maintenance. This section provides the instructions essential for maintenance of the equipment and indicates the maintenance activities which perform the work. It lists all required inspections and tests and gives the bench check procedures and troubleshooting methods to be used.

Section VI. Field Maintenance. The instructions for servicing the equipment at field-maintenance levels are presented here. In addition to alinement and parts removal procedures, information is given for checking

unit functions by means of performance tests. Procedures for trouble isolation are also detailed to assist in localizing defective or malfunctioning parts to specific areas or circuits.

Section VII. Diagrams. This section contains schematics, wiring diagrams, cable information; and in some cases, voltage and resistance data to be used in checks of the particular set and components.

Illustrated Parts Breakdown

This type of publication provides a variety of information essential in repair and maintenance. The principal content consists of exploded views of the major assemblies, subassemblies, and components of the equipment. Each illustration is keyed and referenced to corresponding sections of the text, which supply pertinent information concerning the parts shown. The items specified include the names of the parts, the manufacturer's numbers, descriptions, the stock numbers by which they may be procured, similar parts used in the unit, and any other information which may be necessary.

Electronic Material Changes (EMC)

These are issued by the Bureau of Aeronautics to disseminate technical instructions for addition, removal, or replacement of parts, or for modification of circuits in electronic equipment. Modification of electronic material is normally limited to parts, assemblies, subassemblies, units, and interconnecting wiring. Compliance with EMC's is mandatory and must be done as directed in the particular Changes. A listing of EMC's in effect is contained in the *NavAer Publications Index,* Part I.

Electronic Material Bulletins (EMB)

These papers, which are also issued by the Bureau of Aeronautics, promulgate technical information on operation, inspection, alinement procedures, and maintenance methods; and like EMC's, they are also listed in Part I of the Publications Index.

Instructions and Notices

In many cases, new information pertaining to missiles, missile procedures, and training techniques is issued by means of instructions or notices. The Navy Directive System, as described in SecNav Instruction 5215.1A, is used to classify instructions and notices according to subject areas, each of which is assigned a number to facilitate reference. The following list of subjects and associated numbers are those of particular interest for the GF:

1. Guided Missiles 8810
   a. Air-to-air 8811
   b. Air-to-surface 8812
   c. Air-to-underwater 8813
   d. Surface launched 8820
2. Guided Missile technical training . . 3552
3. Guided Missile launchers 8390
4. Guided Missile countermeasures . . 3432
5. Guided Missile fire control 8260

Permanent directives applicable to naval activities supporting the aeronautical program are issued by means of Bureau of Aeronautics instructions, which pertain to policy, administration, and aircraft operation. BuAer notices cover much the same subject matter as BuAer instructions but are of a temporary nature.

Digest of U. S. Naval Aviation Electronics

This magazine is prepared and published monthly by the Naval Aviation Electronics Service Unit (NAESU). It covers all aspects of aviation electrical and electronic equipment including operation, maintenance, installation, and supply. It is an excellent source of new information as well as new ideas pertaining to older equipment. In many cases it provides the GF the first contact with the details of new circuitry and new devices. It also recounts the latest procedures developed by NAESU for improved methods of testing, calibration, alinement, and similar operations with electronic equipment. The Digest is a very important part of the technical library and files of back copies should be available for ready reference.

Records

Missile-division personnel are required to keep accurate and current records which serve a number of purposes. The records supply concise descriptions of the internal functioning of the division, render valuable aid in administering the division, and provide accurate

sources of information for use in making reports.

The records which concern the missileman directly are those reflecting the histories of repairs, modifications, and operation of two major classes of equipment—missiles and missile test devices. Missile records deal, in the main, with the time of receipt of missile sections, units, and components; dates of assembly; the tests performed; and the final disposition. The entries in typical test-equipment records include operating time, failures encountered, repairs made, and all modifications and changes performed.

MISSILE RECORDS

The submission of accurate and complete records to cognizant activities is the principal source of information concerning utilization and past performance of missiles and associated equipment. With an adequate supply of information, necessary steps can be taken to meet the constant demand for improved missile reliability since the major features of performance can then be analyzed, classified, and the pertinent facts made available to manufacturers and design personnel.

To supply all needed information, a great number of record forms have been developed to trace the course of a particular missile from initial receipt to final launch. In combination, the various records assist in establishing those areas in which the system may require revised specifications, improved design, or other types of modification. The types of missile records usually kept by the GF are described in the following paragraphs.

Receipt, Inspection, and Check Record

In most operating activities, newly received missile sections are checked on arrival to determine whether transit damage or other defects are present. Each package is carefully inspected and the guidance-control section is given a systems test, when possible. A record of receipt, together with the results of the initial inspection and test, are entered in a logbook which accompanies each missile. The entries are made in the part of the log designated for receipt and inspection and show the inspecting activity, the date, and the results of testing. While this record is usually an integral part of the missile log, it is also required that a separate record of this kind be made and kept on file in the missile shop.

Component Record

When packaging is such that the sections contain replaceable, plug-in components, a number of spare components are usually supplied with each missile. These units must be maintained on inventory until expended and complete maintenance and inspections records kept. The records indicate items such as date of receipt, defects noted, any failures revealed by component tests, causes of failures, associated effects, and similar information.

Service Record

The form shown in figure 12-1 is an example of the type used for recording the results of tests made on missiles following captive-flight maneuvers. These flights, in which missiles are carried but not fired, are made for pilot-training purposes and also to evaluate the ability of the missiles to withstand the forces to which equipments on carrier-based aircraft are normally subjected. The form illustrated provides an easy method of recording the results of numerous postflight checks on many missiles performed over a considerable period of time. In addition, it also serves as reference information on the performance of the test equipment involved.

In the first two blocks (fig. 12-1) the entires identify the originating activity and the type of missile under test. Block 3 is used to designate the type, serial number, and calibration date of the test set employed. The data required for the following blocks include date of check; the serial number of the item tested or inspected and the operation performed; operating time on external or internal power; test results; failure indications and description; and finally, the action taken together with appropriate remarks.

The test results are shown as either GO or NO-GO. If the NO-GO indication is given, it is necessary to state whether the trouble is in the missile, in the test equipment, or due to other causes. The information provided by service records assists evaluating activities in determining the most frequent types of failures and in suggesting remedies and corrections both to missile and to test equipment. They are also used in determining reliability rates and the ability of specific missile types to withstand rugged handling and operations such as catapult takeoffs and arrested landings.

GUIDED MISSILE SERVICE RECORD

NAVORD FORM 2774 (New 5-58)

SECURITY CLASSIFICATION

SUBMIT TO

Commanding Officer (Code 65)
U.S. Naval Ordnance Laboratory
Corona, California

REPORT SYMBOL BUORD 8800

2. ORIGINATING ACTIVITY	2. MISSILE OR ASSBY (*Name, Configuration and or S/N*)
	3. TEST SET (*Type, S/N and Calibration Date*)

4. DATE	5. ITEM AND OPERATION	6. OP. TIME (*Minutes*)		7. TEST RESULTS (*Check one*)					8. FAILURE INDICATIONS	9. ACTION TAKEN AND REMARKS
MO DAY YR	SERIAL NUMBER OF ITEM TESTED OR INSPECTED AND OPERATION PERFORMED	EXTERNAL POWER	INTERNAL POWER	GO	NO GO: ITEM	NO GO: T.E.	NO GO: PERS.	NO GO: MISC.	LIGHT NUMBER, METER READING, DAMAGE OTHER ((*Describe*)	1. ADJUSTMENT TO MISSILE, ASSEMBLY, OR T.E. 2. REJECTION OF ITEM a. TOTAL FIELD OP, TIME OF REJECTED ITEM b. IDENTIFICATION (*Ser. & stock no. of old and new item*) c. DISPOSITION OF REJECTED ITEM

Figure 12-1.—Guided Missile Service Record.

Assembly and Loading History

This record is primarily a checkoff chart which indicates the course of a missile from stowage breakout to loading aboard an aircraft. The history, which starts with assembly of the missile, indicates the key serial numbers of sections, motors, fuzes, and other major items. It follows the missile through the test area to ready-service areas (where missiles are stowed complete except for certain ordnance items) and then up to the aircraft.

The form is divided into two sections. The first section contains all the assembly data from breakout to ready stowage. The second section lists further assembly steps from stowage up to loading. As each step is performed, it is checked off by the crew supervisor. When the final signature is added, this indicates that all steps have been completed and the missile is ready for loading. The assembly and loading record then becomes a part of the missile log.

Missiles returned from flight and sent to ready stowage are provided with new record blanks. The second sections of these blanks are checked off again as the corresponding missiles are readied for second flights. This record form, in addition to providing the history of a missile, also enables the loading crew to determine immediately whether or not a particular missile is ready for loading by noting the presence or absence of a final signature on the checkoff sheet. A separate form, for loading crews, is based on the same format to facilitate and expedite handling.

Missile Logs

The missile log is an essentially complete history of the weapon from the time of acceptance until the time of expenditure. An example of the form provided for one type of missile is shown in figure 12-2. The log, which is usually packaged in one of the containers in which the missile sections are shipped, may or may not contain entries when received by the operating activity. However, the first contact the missileman has with this record is generally upon receipt of the missile.

When completed, the log indicates past difficulties encountered with the particular missile and records the changes made in it. It lists the serial numbers of the components, and gives the results of the tests performed. Upon expenditure of a missile, the corresponding log is returned to the cognizant bureau.

Postflight Abort Record

Abort records are required for missiles which, for any reason, fail to leave the launcher and must be returned for de-arming. On these occasions, these records are extremely important since they assist in protecting personnel and equipment against accidental detonation of the missile. The form contains a checkoff list which indicates the necessary procedures to be taken, the order in which the steps must be taken, and the checks required to insure that the weapon has been rendered harmless. Thus, the record is basically a safety device.

TEST EQUIPMENT RECORDS

Missile test equipments, like all complex devices, are valueless when inoperative. They require rigid inspection, adequate preventive maintenance, and competent repair if maximum utilization is achieved. This, in turn, requires complete records, which in combination, show the history of each test set, indicate the changes and repairs made, and reflect daily performance.

Test-equipment records are kept under several systems; the most common being the ledger, or log; record cards; and daily record sheets. The following discussion concerns typical forms, the information they contain, and the manner in which they may be used in maintenance and repair.

Equipment Repair Service Record

The repair service record is kept on a one-time only form and is used when an equipment experiences a failure. In addition to identifying information, the record shows the nature of the trouble, the corrective action taken, the parts used (with stock numbers), and other entries which refer to the results of the failure. An example of a typical equipment service record is shown in figure 12-3. Note that space is provided at the lower part of the sheet for the signer to indicate followup action, thereby signifying that the necessary failure reports have been filed and adjustments have been made in stock records. A periodic review of the equipment service records indicates the nature of the work performed in the shop, the

LAND-NOLC-114
TRIAL (257)

SIDEWINDER GUIDANCE AND CONTROL UNIT SERVICE LOG

I. FACTORY ACCEPTANCE RECORD

CLASSIFICATION

G & C Unit Serial No.	Manufacturer	Date of Acceptance	Operating Time at Acceptance

Functional Deviations and Waivers at Acceptance

II. FIELD SERVICE RECORD

INSTRUCTIONS

1. Enter data of each inspection or operation of the Unit.
2. Insert pen recordings of each test in the Service Log Envelope.
3. Upon rejection of the unit, place this Service Log and the Test Records in the shipping container with the Unit.
4. Upon expenditure of the missile, forward this Service Log and Test Records within 15 days to: COMMANDING OFFICER (CODE 65), U.S. NAVAL ORDNANCE LABORATORY, CORONA, CORONA, CALIFORNIA.

TEST DATE	REPORTING ACTIVITY	TEST SET TYPE	RESULTS (Check One)		REMARKS (Note Reasons for Rejects)
			Accept	Reject	

Figure 12-2.—Guided missile log.

ELECTRONIC REPAIR SERVICE RECORD

Date ______________

Equipment Model ___________ Unit Name ___________

Serial Number ___________ Unit Type ___________

Unit Serial ________

Nature of trouble

____
(Operator)

Corrective Maintenance work:

Work completed ___________ (Date) Time to complete work ___________ (Hours)

Replacement Parts Used:

Circuit Symbol	Description	Life Hours	Serial No.	Mfg.	Stock No.

Technician _______________________________
(Name and Rate)

Record of Entries:

Equipment History Card ______________
Electronics Failure Report ______________
Inventory Record ______________
New Part Ordered ______________

Completed _______________________
(Name and Rate)

Figure 12-3.—Equipment repair service record.

man-hours expended, the material used, and other information of related nature.

Maintenance Histories

Maintenance histories of test equipment are usually kept in log or journal form. The history begins upon receipt of the equipment when entries concerning the type of device and all essential serial numbers are made. Subsequent entries are made in chronological order. These indicate all field changes and modifications, failures, malfunctions, repairs, operating time, and any incidental data serving to point out peculiarities of the equipment. The maintenance history is thus an excellent source of report material. It uncovers chronic troubles and inherent weaknesses and indicates the value of the equipment to the activity by showing the ratio of operational time to down time. The history also serves as a valuable training aid for use in familiarizing personnel with the operation and maintenance procedures of the device.

The log form of maintenance history is generally employed with major equipments such as missile systems test sets. Records of smaller items (such as voltmeters, oscilloscopes, and signal generators), which have low failure rates, are usually made on history cards. An example is the Electronic Equipment History Card, NavShips 536, shown in figure 12-4. This form is used to record failures and other pertinent information which can be used to complete the necessary Electronic Failure Reports (EFR's). As shown in the illustration, the card provides spaces for identifying information and for much of the data necessary to maintain an accounting of the equipment.

Postoperative and Preoperative Check Records

In the operation of many types of large, complex test sets, particularly those which involve a number of controllable features, certain conditions must be met before the equipment is ready for test purposes. Also, when the test has been completed, the controls must be set to positions specified in the handbook. To insure that these conditions have

Stocked in CDS ELECTRONIC EQUIPMENT HISTORY CARD NAVSHIPS 536 (Rev. 9-48)

Equipment Model Designation	Equip. Ser. No.	Name of Unit and Type No.	Card No.

Name of Contractor	Contract No.	Date Installed	Serial No. of Unit

Location	Installing Activity

Spare Parts	Box No. and Location	Instr. Bk. On Board (Check) ☐

Date	Nature of Trouble (Or F. C. No. and Title)	Cause of Failure Brief Description of Work Done	Name of Part	Circuit Symbol	Navy Stock No.	Life Hours	Date NavShips-383 Mailed

16—53056-1

Figure 12-4.—Electronic Equipment History Card, NavShips 536.

been met, many activities employ preoperative and postoperative checksheets. These forms contain blanks for identifying the units, listing key voltages and currents, and include check-off lists of switch positions to be set up prior to and after completion of missile checkout.

Reports

Reports are required from various departments and command levels to compile statistical and other data regarding implementation of various directives. Reports are also prepared for evaluating the effectiveness of activities and branches to check the desirability of various policies and procedures. When analyzed, these reports provide the basis for material allowances, service changes and bulletins, and electronic material changes and bulletins. In addition, reports are used to provide information regarding the serviceability of aircraft materials and equipments and as sources of information pertaining to changes in equipment design.

MATERIAL RELIABILITY REPORTS

There are two basic forms used for reporting failures, faults, and malfunctions of aeronautical material. These are entitled Failure, Unsatisfactory or Removal Report, NavAer 3069; and Electronic Failure Report, DD 787. Both are simplified check-box forms that require little detailed writing. Provision is made to amplify both reports by the addition of narrative data when conditions demand. For simplicity, the 3069 form is designated as FUR and the DD 787 as EFR.

Electronic Failure Reports (EFR)

The purpose of the EFR (fig. 12-5) is to provide the Bureau of Aeronautics with up-to-date information on equipment failures and reliability. They are submitted for all failures or unsatisfactory conditions of electron tubes and electronic parts and also for electrical parts of systems or sets.

The EFR is prepared by the technician who actually located the trouble or repaired the

REPORT THE FAILURE OF ONLY ONE PART OR TUBE ON THIS FORM

1 REPORT NO.	2. REPORTING ACTIVITY	3. REPAIRED OR REPORTED BY (NAME)	4. DATE OF FAILURE
5. EQUIPMENT INSTALLED IN (TYPE AND NO.)	6. TIME METER READING OR INSTALLATION LOG TIME	7. WAS MISSION ABORTED? ☐ YES ☐ NO	8. OPERATIONAL CONDITION

EQUIPMENT	9. MODEL DESIGNATION AND MOD. NO.	10. SERIAL NO.	11. CONTRACTOR	12. CONTRACT OR ORDER NO.
COMPONENT (MAJOR UNIT)	13. MODEL DESIGNATION AND MOD. NO.	14. SERIAL NO.	15. CONTRACTOR	16. CONTRACT OR ORDER NO.
ASSEMBLY OR SUBASSEMBLY	17. ASSEMBLY AND MOD. NO.	18. SERIAL NO.	19. MANUFACTURER	20. (LEAVE BLANK)

PART DATA	21. PART NAME OR TUBE TYPE	22. STOCK NO. (FAILED ITEM)	23. PART REF. DESIG. (V-101, R-101, ETC.)	24. REPAIR TIME (MAN-HOURS)
	25. HOURS IN SERVICE	26. MANUFACTURER OF FAILED PART	27. SERIAL NO.	28. WAS REPLACEMENT PART AVAILABLE LOCALLY ☐ YES ☐ NO

29. FIRST INDICATION OF TROUBLE	30. CHECK TYPE(S) OF TUBE OR PART FAILURE			31. CAUSE OF FAILURE
1 ☐ INOPERATIVE	007 ☐ ARCING	001 ☐ GASSY	790 ☐ OUT OF ADJUST.	2 ☐ FAULTY PACKAGING
2 ☐ INTERMITTENT	710 ☐ BEARING FAILURE	300 ☐ GROUNDED	006 ☐ SHORTED	5 ☐ MISHANDLING
3 ☐ LOW PERFORMANCE	780 ☐ BENT	380 ☐ LEAKAGE	770 ☐ SLIP RING OR COMMUTATOR FAILURE *	6 ☐ INSPECTION OR TEST
4 ☐ NOISY	040 ☐ BINDING	730 ☐ LOOSE		1 ☐ NORMAL OPERATION
5 ☐ OFF FREQUENCY	070 ☐ BROKEN	004 ☐ LOW GM OR EMISSION	018 ☐ TESTED OK DID NOT WORK	3 ☐ STORAGE
6 ☐ OUT OF ADJUSTMENT	720 ☐ BRUSH FAILURE	750 ☐ MISSING		7 ☐ ASSOCIATED FAILURE-EXPLAIN
7 ☐ OVERHEATING	080 ☐ BURNED OUT	008 ☐ NOISY	020 ☐ WORN EXCESSIVELY	4 ☐ OTHER
8 ☐ UNSTABLE	130 ☐ CHANGED VALUE	450 ☐ OPEN	☐ SEE INSIDE FLAP FOR ADDITIONAL CODES	32. WAS THE PART REPLACED DURING PREVENTIVE MAINTENANCE? ☐ YES ☐ NO
9 ☐ OTHER	170 ☐ CORRODED	099 ☐ OTHER		

33. REMARKS *(Continue on reverse side if necessary)*

DD (1 AUG 54) **787** ELECTRONIC FAILURE REPORT

A15907

Figure 12-5.—Electronic Failure Report (EFR).

equipment. A report must be submitted for each failure that occurs, or upon determining that a part or tube is defective or unsatisfactory for any reason. In cases where two or more associated parts are found to be defective and doubt exists as to which part is primarily at fault, each part must be reported separately. Each report must refer to all other reports of the associated failure and all reports of multiple failures (involving the associated parts) should be clipped together to assist in rapid evaluation.

In general, EFR's are submitted without amplifying remarks. However, when the reporting activity is of the opinion that the reported conditions may be more readily evaluated by the inclusion of narrative comments, such may be added in the remarks space of the form. These comments may be continued on the reverse side or on a separate sheet of bond paper to be attached to the EFR. The remarks should include a description of the conditions preceding the failure or malfunction and when possible, a brief statement of remedial procedures recommended. Unnecessary use of the remarks space for meaningless comments should be avoided since this delays data processing.

EFR's should be submitted within one day following the occurrence of the failure. However, those reports that include amplifying remarks and photographic enclosures may be delayed up to three days. When preparing these reports, it is necessary to make all entries pertinent to the particular case so that maximum benefit can be obtained from the system. The entries should be made in accordance with NavAer Instruction 00.58B, or with the latest change.

Failure, Unsatisfactory or Removal Report (FUR)

This report is prepared on Form NavAer 3069 (fig. 12-6), which is provided in two types. One is an eight-page, multipart, carbon-interleaved set; the other is a single-copy FUR.

The multiple-copy FUR is used to report failures in sets, units, or assemblies when the faulty equipment must be turned in for repair or credit and replaced by new equipment drawn from supply. Under these circumstances, the preparation of Form DD 1150 (Request for Issue or Turn In) is not required and the FUR "RM" copies become official accountable documents. The single-copy FUR is used when no turn-in to supply is made.

The multiple-copy FUR is comprised of eight sheets which form a pad or set. The sheet dispositions are: FUR Center (1), File (1), documents for returning material (3), memorandum request for material (2), and tag (1). Thus the report consists of an original plus seven copies; the entries should be made with a typewriter or with a ballpoint pen.

Amplifying remarks are to be noted in the space provided on the FUR and may be continued on a separate sheet when this is necessary to present a complete explanation of the failure. The inclusion of amplifying remarks changes the classification of report from FUR to AMPFUR (amplified FUR). When, in the opinion of the reporting activity, the subject requires immediate remedial action, the report may be assigned priority as an URGENT AMPFUR. When the subject relates directly to flight safety, the report will be assigned priority as a FLIGHT SAFETY AMPFUR.

All AMPFURS, URGENT AMPFURS, and FLIGHT SAFETY AMPFURS receive individual attention, whereas regular FUR's are used for quantitative analyses. Complete information on these reports is provided in the instruction mentioned above (NavAer 00.58B).

SPECIAL REPORTS

Captive Flight/Firing Report

A system of collecting captive flight and firing data on missiles is illustrated by the missile flight report shown in figure 12-7. The use of a report of this nature is threefold in that it allows the cognizant activity to:

1. Accumulate in service data for the evaluation of the overall missile system reliability and effectiveness.
2. Identify factors adversely affecting reliability and serviceability including the factor of captive flight time.
3. Recommend to the appropriate bureau, action for the improvement of design and performance of equipment, the correction of material defects, and the revision of procedures and specifications.

The form, as shown in figure 12-7, provides for the following information by section:

Section 1. Identification of the activity, the missile and missile components, and time in flight.

PRESS HARD ★U. S. GOVERNMENT PRINTING OFFICE 1957-411987 YOU ARE MAKING OUT ______ AN EIGHT PART FORM PRESS HARD

1. REPORTING ACTIVITY	2. REPORT SERIAL	3. DATE OF TROUBLE	4. MAJOR COMMAND (Enter number in space at right) 1 - LANT 3 - NABS 5 - FLAW 7 - NART 9 - MATS 2 - PAC 4 - NATRA 6 - R & D 8 - BAR 0 - OTHER
VS - 137	187	2/8/57	1

5. ITEM IDENTIFICATION (Stock Number)	6. MFGR'S. CODE	7. ITEM PART NUMBER
R82-ARBN-E 1046	ARBN	E- 1046

8. ACCT. CODE	9. ITEM NOMENCLATURE	10. QUANTITY	11. OVERHAULED BY (Enter number in space at right) 1. ALAM 3 - CORP 5 - LAKE 7 - NORIS 9 - QUON. 2 - CH. PT. 4 - JAX 6 - NORF 8 - PENS 0 - OTHER
R	ACTUATOR	1	6

12. AIRCRAFT/MISSILE/AC/CATAPULT	13. SYSTEM/ENGINE/ACCESSORY	14. AIRCRAFT/MISSILE/AC/CATAPULT	15. ENGINE/ACCESSORY
MODEL FJ-3M	MODEL — — —	BUNO 126183	SER. NO. — —

16. TIME (Hours)	17. OPERATING BASE	18. CONTRACT NUMBER	19. TROUBLE RESULTED IN (Check as more than two)
86	QUONSET POINT	NOAS 52-1862	0 AAR 11 FLIGA 2 FLAME-OUT 3 ENGINE FAILURE

20. HOW TROUBLE NOTICED
- [X] INOPERATIVE
- 1 INTERFER./BINDING
- 2 EXCESS. VIBRATION
- 3 UNSTABLE/SURGING
- 4 LEAKAGE
- 5 RPM OUT-OF-LIMITS
- 6 TEMP. OUT-OF-LMT
- 7 PRESS. OUT-OF-LMT
- 8 TROUBLE SHOOTING
- 9 PREVENTIVE MAINT.
- 11 OTHER
- 12 NOT REMOVED-UNSAT. (Amplify)

21. WHAT IS PART CONDITION
- 0 CHAFED
- [X] BROKEN
- 2 CRACKED
- 3 DISTORTED
- 4 SCORED
- 5 EXCESSIVE WEAR
- 6 DISCOLORED
- 7 OUT OF TOLERANCE
- 8 CORRODED
- 9 O.K.
- 11 CANNOT DETERMINE
- 12 OTHER (Amplify)

22. CAUSE OF TROUBLE
- 0 DESIGN DEFICIENCY
- 1 OP. TECH./ADJ.
- [X] NORMAL USE
- 3 FAULTY MFG/INSPEC.
- 4 DEFICIENT MAINT/O.H.
- 5 DAMAGED ON RECPT.
- 6 WEATHER CONDITION
- 7 FLUID CONTAMINATION
- 8 FOREIGN OBJ/COMBAT
- 9 OTHER PARTS
- 11 FAULTY PRESERV.
- 12 UNDETERMINED /OTHER (Amplify)

23. CIRCUMSTANCES

Special
- 0 FOLLOW-UP REPORT
- 11 HIGH TIME REMOVAL
- 12 MISSION ABORTED

Environment
- 1 SANDY/DUSTY
- 2 ARCTIC
- 3 TROPIC
- 4 ARID

Trouble Discovered During
- 5 FLIGHT OPS
- [X] GROUND OPS/TEST
- 7 MAINTENANCE
- 8 PRIOR PART INSTALL.

24. DISPOSITION OF FAILED PART (Do not check if not removed)
- [X] RETURNED TO SUPPLY
- 1 REPAIRED/REINSTALLED
- 2 SURVEYED (Lost, Missing, or Destroyed)
- 3 HOLDING 30 DAYS______ (Show BASO or date returned to supply)
- 4 RELEASED FOR PRIORITY INVEST.______ (Name of O&R)
  PER:______ (Ref. document specifying invest. O&R)
- 5 TO CONTRACTOR:______ (Name of contractor)
  VIA:______ (Signature contractor's local rep.) (Date)

FINAL DISPOSITION:______ (Ref. doc. advising ultimate return to supply)

25. STATEMENT OF TROUBLE/CORRECTIVE ACTION (Check box only when publication as FUR Digest Phrase is desired) [ ]

26. AMPLIFYING REMARKS (Attach additional sheets, sketches, and photographs, as appropriate)

27. REPORT IS
- [X] FUR
- 1 AMPFUR
- 2 URGENT AMPFUR
- 3 FLIGHT SAFETY AMPFUR
- 4 PRIORITY DIR (O&R use only)

FAILURE, UNSATISFACTORY OR REMOVAL REPORT NAVAER - 3069 (REV. 8-56)

28. SIGNATURE	29. RANK/RATE	30. DATE
John D. Penrod	LT USN	2/8/57

FUR (Mail to FUR Center)

Figure 12-6.—Failure, Unsatisfactory or Removal Report (FUR).

Section 2. Firing results including information on launching aircraft, target, and missile performance.

Section 3. Remarks concerning weather, target maneuvers, or other information to help evaluate the performance.

Special instructions concerning the proper completion of these and similar forms are issued by the Chief of the Bureau concerned together with methods of transmittal of completed forms.

Maintenance Usage Data Reports

Reports of this nature are essential in providing a properly functioning supply and replacement system. The reports are required in order that Aviation Supply may make timely revisions to applicable allowance lists and provide adequate ranges and quantities of items for the support of missiles and missile systems.

It is expected that the use of these data involved will:

a. Facilitate the critical review, evaluation and effectiveness of Allowance Lists.

b. Achieve a better level of maintenance support during the early months of operation of new model equipment in the fleet.

c. Provide more effective information for use in the determination of requirements during provisioning of new equipments.

Maintenance usage is defined as the quantity of each part or component removed and/or replaced during the reporting period. The submission of these data is required by fleet activities and operating units concerned with equipments listed in command instructions and which receive ASO Maintenance and

SIDEWINDER CAPTIVE FLIGHT/FIRING REPORT
11ND-NOLC-87 (Rev. 3-59)

CONFIDENTIAL
(when filled in)

Date:

Mail to: COMMANDING OFFICER, NAVAL ORDNANCE LABORATORY (CODE 65), CORONA, CALIF.

1. SHIP OR STATION
2. SQUADRON No.
3. AIRCRAFT Type BU. No.
4. LAUNCHER Type ________ Position ________
5. GUIDANCE AND CONTROL Ser. No.
6. INFLUENCE FUZE Ser. No.
7. CONTACT FUZE Ser. No.
8. WARHEAD Ser. No. ☐ Live ☐ Exercise
9. CAPTIVE FLIGHT TIME Hours

FIRING RESULTS

10. AIRCRAFT ALTITUDE AND SPEED ________ ft. Mach No. ________
11. AIRCRAFT ATTITUDE AT FIRING ☐ Level ☐ Dive ☐ Climb ☐ Turn
12. ANGLE OFF TARGET TAIL (Tail-on = 0°) ________ Deg.
13. TARGET (check flares, if used) Type ________ ☐ Flares
14. TARGET SLANT RANGE ________ ft. ☐ Radar ☐ Est.
15. TARGET ALTITUDE AND SPEED ________ ft. Mach No. ________
16. TARGET BACKGROUND
17. ANGEL OF SUN FROM TARGET ________ Deg. ☐ Over 90°
18. SIGNAL TONE STRENGTH ☐ Normal ☐ See Remarks
19. LAUNCHER ACTION/DELAY ☐ Normal ☐ See Remarks
20. MISSILE PERFORMANCE ☐ Normal ☐ See Remarks
21. CONTACT HIT/MISS DISTANCE ☐ Hit ________ ft. Direction ________
22. FUZE/WARHEAD ACTION ☐ Normal ☐ Self-Destruct ☐ None
23. TARGET DAMAGE ☐ Total ☐ Partial ☐ None

24. REMARKS (weather, target maneuvers, unsatisfactory & explanatory info, etc.)

(Pilot)

CONFIDENTIAL *(when filled in)*

Figure 12-7.—Captive Flight/Firing Report.

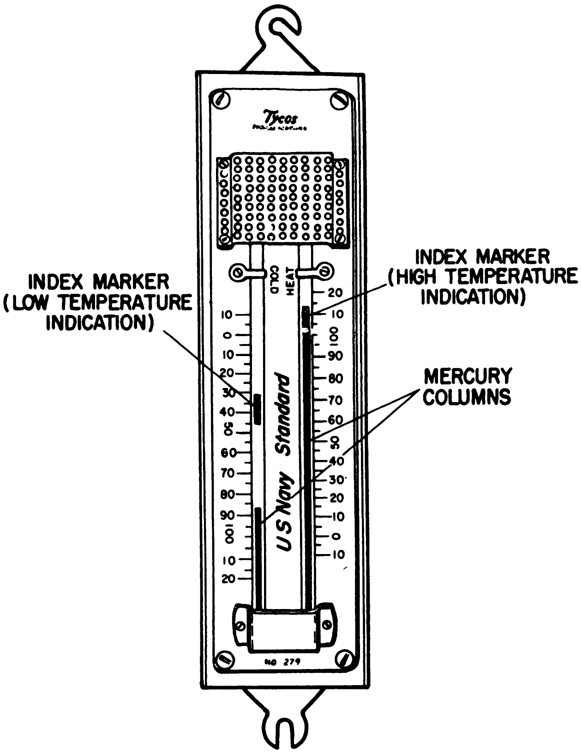


Figure 12-8.—Maximum-minimum thermometer.

DAILY MAGAZINE TEMPERATURE

NOTE: To be submitted to O.O.D. at 1200 daily.

U.S.S. TRACEN	DATE 1 APRIL 59
MAXIMUM 84°	IN A-304 M
MINIMUM 69°	IN A 204 LM

INSPECTED MAGAZINES' CONDITION
OK

INSPECTED BLOWERS' CONDITION
OK

INSPECTED S.P. INDICES CONDITION
D.P.

REMARKS
NONE

SIGNATURE *(Gunnery Officer)*
H E Broccia LCDR

Figure 12-9.—Daily Magazine Temperature Report.

Operational Data Report Forms. Detailed instructions for executing the report will be included with the forms.

In general, the GF is concerned mainly with usage data concerning Section R material. Section R Usage Reports are submitted quarterly listing total quantity of each item used, including repaired and salvaged items in direct support of the number of assigned equipments. These reports are submitted by groups and include all appropriate equipments of each group. It is well to remember that Section R Allowance Lists are compiled from these Usage Reports. Therefore, it is to the benefit of the activity concerned to insure that these reports are properly and adequately prepared so that future allowance lists meet maintenance requirements. In general, the usage data reporting activity for any particular reporting period will be the paramount activity rendering maintenance support during that period. Thus, the electronics usage data for deployed squadrons will be reported by the supporting carrier, tender, etc.; whereas the

data for non-deployed squadrons will be reported by the supporting service activity.

Magazine Temperature Reports

Aboard ships and stations, the temperatures of magazines used for storing explosives must be carefully observed and controlled. In those cases where missilemen have custody of magazines containing ready-service missiles and missile ordnance equipment, they are required to make daily reports of maximum and minimum temperatures.

The data for temperature reports are provided by maximum-minimum thermometers, one type of which is shown in figure 12-8. At least one and sometimes two of these instruments are placed in the magazine to indicate three items. Present temperature is indicated by the levels of the two mercury columns (about 94 degrees in the figure). The lower end of the index marker in the left mercury column shows the lowest temperature since the last inspection (about 46 degrees in the drawing). The bottom of the index marker in the right column shows the high since the last inspection (slightly above 100 degrees).

The maximum and minimum temperature values are entered in the Daily Temperature Report, an example of which is shown in figure 12-9. In addition to the thermometer indications, the report shows the results of inspections of the general condition of the magazine, the blower, and smokeless-powder indices. When the temperature readings are taken, the thermometer (fig. 12-8) is then reset by moving the steel index markers in the tubes by means of a magnet until they rest on the tops of the mercury columns.

QUIZ

1. The guided missile technical library in an activity
   a. is optional at the discretion of the division officer
   b. contains technical manuals but no letter publications
   c. receives a grade in annual inspection
   d. is of little importance to trained technicians

2. The Naval Aeronautic Publications Index is issued by authority of the
   a. Chief, Bureau of Aeronautics
   b. Chief of Naval Operations
   c. Bureau of Aeronautics
   d. Aviation Supply Office

3. The Naval Aeronautic Publications Index contains publications originated by the
   a. Chief of Naval Operations
   b. Bureau of Ordnance
   c. Deputy, Chief of Naval Operations for Air
   d. all of the above are correct

4. The Naval Aeronautic Publications Index, Part I, is referred to as the
   a. Numerical Sequence List
   b. Equipment Applicability List
   c. Aircraft Applicability List
   d. Allowance List

5. The structure of the guided missile is listed in the Naval Aeronautic Publications Index under
   a. Part III, in group 08, Airframes
   b. Part III, in group 08, Guided Missiles
   c. Part II, in group 01, Airframes
   d. Part II, in group 02, Guided Missiles

6. The manual containing the primary source of authoritative information on specific equipment is called the
   a. Digest of Aviation Electronics
   b. Handbook of Service Instructions
   c. Illustrated Parts Breakdown
   d. Technical Publications

7. Section IV of the Handbook of Service Instruction usually deals with the
   a. description and leading particulars
   b. theory of operation
   c. preparation for use and reshipment
   d. special test equipment and special tools

8. The principal contents of the Illustrated Parts Breakdown catalog consists of
   a. exploded views of major assemblies, subassemblies, and components
   b. alinement and parts removal procedures
   c. wiring diagrams and parts locations
   d. bench check procedures and troubleshooting methods

9. Permanent directives applicable to naval activities supporting the aeronautical program are issued by means of
   a. Bureau of Aeronautics notices
   b. Aviation Supply Office orders
   c. Aviation Supply Office bulletins
   d. Bureau of Aeronautics instructions

10. Transit damage or other defects which are present on newly received missiles should be logged in the
    a. assembly and loading history
    b. guided missile service record
    c. guided missile "Report of Damaged Components"
    d. missile logbook

11. Spare plug-in components are usually supplied with certain missiles, and these units are maintained on inventory until expended. Complete records of maintenance and inspection of them are initiated
    a. when defects are discovered during tests
    b. when they are responsible for an abort
    c. upon receipt of the units
    d. upon putting the units into service

12. A record of missile tests which may also serve as reference information on the performance of the missile test equipment is the guided missile
    a. Component Record
    b. log
    c. Service Record
    d. Assembly and Loading History

13. Missile evaluating activities are aided in determining most frequent types of failures, reliability rates, and the ruggedness of specific missile types by the Guided Missile
    a. Equipment Repair Service Record
    b. Service Record
    c. log
    d. Test Equipment Record

14. A record which is primarily a checkoff chart, yet shows key serial numbers of major components is the Assembly and Loading History; it
    a. contains assembly data from breakout to ready stowage
    b. lists assembly steps from stowage to loading
    c. eventually becomes a part of the missile log
    d. is described by each of the foregoing statements

15. The guided missile log
    a. receives its first entries from the operating activity
    b. is an essentially complete history of the weapon
    c. is retained by the operating activity when the missile has been expended
    d. records difficulties and repairs but not tests

16. A form which contains a checkoff list and is extremely important as a safety device is the
    a. Magazine Thermometer Temperature Report
    b. guided missile log
    c. postflight abort record
    d. Assembly and Loading History

17. Maximum utilization of missile test equipment requires complete records which show
    a. history of the set
    b. changes and repairs effected
    c. daily performance of the set
    d. all of the above

18. The Equipment Repair Service Record is kept in__________form.
    a. journal or ledger
    b. daily record
    c. one-time-only
    d. log

19. A record for major test equipments which is analogous to the missile log is the
    a. Material Reliability Report
    b. Electronic Equipment History Card, NavShips 536
    c. Equipment Repair Service Record
    d. Maintenance History Journal

20. A well-kept maintenance history serves
    a. to point out peculiarities of the equipment
    b. as a valuable training aid
    c. as an excellent source of report material
    d. toward all the foregoing ends

21. Preoperative and postoperative check sheets are particularly desirable aids to correct operation of
    a. large, complex test sets
    b. all electronic test equipment
    c. any equipment exhibiting a low failure rate
    d. synchroscopes and signal generators

22. In cases of electronic failure involving several associated parts or items,
    a. all related items are reported on one EFR
    b. each item is reported on a separate EFR, which refers to all others
    c. each item is reported on a separate EFR, which refers to the EFR preceding it in the maintenance log
    d. EFR's must be prepared by the shop chief

23. Efficiency of the supply system, availability of replacement parts, and reliability of material all are promoted by the correct use of EFR's. This is possible because the EFR
    a. is executed on the spot by the technician who locates the trouble
    b. is submitted within a maximum of three days following a failure
    c. can be rapidly processed or evaluated
    d. is described by all of these statements

24. The Failure, Unsatisfactory or Removal Report (FUR) is prepared on one of______ types of form.
    a. two
    b. four
    c. seven
    d. eight

25. Collection of in service data for missile evaluation, identification of factors adversely affecting missile performance, and improvement of missile design and performance are facilitated by correct employment of the________Report.
    a. Captive Flight/Firing
    b. Maintenance Usage Data
    c. Failure, Unsatisfactory or Removal
    d. Electronic Failure

26. Most essential of the following in providing a properly functioning supply and replacement system are________Reports.
    a. Maintenance Usage Data
    b. Captive Flight/Firing
    c. Material Reliability
    d. Electronic Failure

27. It is to the benefit of the activity concerned to insure that Usage Reports are properly and adequately prepared because
    a. Section R Allowance Lists are compiled from Usage Reports
    b. submission of this data is required by fleet activities and operating units
    c. these reports are submitted by groups and include all appropriate equipment of each group
    d. the GF is concerned mainly with Section R material

28. Data for magazine temperature reports are provided by maximum-minimum thermometers, which indicate________temperatures.
    a. two
    b. three
    c. four
    d. five

29. From the maximum-minimum thermometer in figure 12-8, a maximum temperature is read at the
    a. bottom of the right-hand marker
    b. top of the left-hand marker
    c. bottom of the left-hand marker
    d. mean position of both markers

30. The maximum-minimum thermometer is of small value when the
    a. humidity is too high
    b. indices are not reset
    c. wrong ends of the markers are used
    d. humidity is too low

APPENDIX I
ANSWERS TO QUIZZES

Chapter 1
DUTIES AND RESPONSIBILITIES

1. b.
2. a.
3. a.
4. d.
5. d.
6. c.
7. c.
8. c.
9. b.
10. b.
11. a.
12. a.
13. c.
14. d.
15. c.
16. b.
17. a.
18. b.
19. b.
20. d.
21. c.
22. a.

Chapter 2
TRANSISTORS AND THEIR APPLICATIONS TO MISSILES

1. a.
2. a.
3. c.
4. d.
5. b.
6. c.
7. d.
8. c.
9. b.
10. a.
11. c.
12. d.
13. a.
14. b.
15. b.
16. c.
17. d.
18. b.
19. a.
20. c.
21. a.
22. a.
23. c.
24. b.
25. a.

Chapter 3
MAGNETIC AMPLIFIERS AND THEIR APPLICATIONS TO MISSILES

1. a.
2. a.
3. b.
4. d.
5. d.
6. b.
7. c.
8. a.
9. d.
10. a.
11. c.
12. c.
13. d.
14. b.
15. d.
16. b.
17. a.
18. d.
19. d.
20. c.
21. d.
22. c.
23. a.
24. d.
25. a.

Chapter 4
SPECIAL ELECTRONIC CIRCUITS

1. a.
2. b.
3. b.
4. c.
5. b.
6. d.
7. c.
8. a.
9. b.
10. b.
11. a.
12. a.
13. c.
14. d.
15. a.
16. d.
17. d.
18. c.
19. c.
20. b.
21. a.
22. a.
23. a.
24. b.
25. d.
26. a.

Chapter 5

MICROWAVE APPLICATIONS IN MISSILE CIRCUITS

1. b.
2. a.
3. d.
4. d.
5. c.
6. a.
7. b.
8. b.
9. d.
10. b.
11. c.
12. c.
13. a.
14. d.
15. a.
16. d.
17. b.
18. c.
19. c.
20. b.
21. d.
22. b.
23. a.
24. d.
25. c.
26. b.
27. c.
28. d.
29. a.
30. a.

Chapter 6

INTRODUCTION TO MISSILE TESTING

1. c.
2. a.
3. a.
4. a.
5. a.
6. a.
7. a.
8. a.
9. a.
10. a.
11. a.
12. a.
13. c.
14. d.
15. b.
16. b.
17. a.
18. a.
19. a.
20. a.
21. a.
22. a.
23. a.
24. c.
25. c.

Chapter 7

SYSTEMS TESTING AND TEST EQUIPMENT

1. b.
2. a.
3. d.
4. d.
5. c.
6. a.
7. b.
8. c.
9. d.
10. a.
11. d.
12. b.
13. c.
14. c.
15. a.
16. d.
17. c.
18. d.
19. b.
20. a.
21. c.

Chapter 8

ELECTRONIC COMPONENT TESTING

1. b.
2. b.
3. d.
4. d.
5. b.
6. a.
7. d.
8. a.
9. c.
10. b.
11. c.
12. a.
13. d.
14. d.
15. a.
16. b.
17. c.

Chapter 9

TESTING ELECTRONIC POWER SUPPLIES

1. a.
2. b.
3. d.
4. c.
5. a.
6. b.
7. d.
8. c.
9. b.
10. c.
11. d.
12. a.
13. b.

Chapter 10

MISSILE WING SERVOMECHANISMS

1. c.
2. a.
3. d.
4. c.
5. d.
6. b.
7. b.
8. c.
9. a.
10. d.
11. c.
12. d.
13. b.
14. d.
15. a.
16. c.
17. d.
18. c.
19. b.
20. b.
21. d.
22. a.

Chapter 11

TESTING CONTROL INSTRUMENTS

1. a.
2. d.
3. a.
4. c.
5. b.
6. a.
7. d.
8. a.
9. c.
10. c.
11. a.
12. d.
13. b.
14. d.
15. c.
16. b.
17. a.
18. c.
19. d.
20. d.
21. c.
22. a.
23. d.
24. b.

Chapter 12

PUBLICATIONS, RECORDS, AND REPORTS

1. c.
2. a.
3. d.
4. a.
5. c.
6. b.
7. b.
8. a.
9. d.
10. d.
11. c.
12. c.
13. b.
14. d.
15. b.
16. c.
17. d.
18. c.
19. d.
20. d.
21. a.
22. b.
23. d.
24. a.
25. a.

APPENDIX II

QUALIFICATIONS FOR ADVANCEMENT IN RATING

AVIATION GUIDED MISSILEMEN (GF)

(Through Change 13)

General Service Rating

Scope

Aviation Guided Missilemen assemble, test, aline, adjust, replace, and repair internal components of air-launched missiles, excluding propulsion systems and ordnance items and hydraulic/pneumatic systems not associated with missile internal guidance and control; operate, test, adjust, aline, calibrate, and repair missile test equipment; supervise and train personnel in testing and repair of guided missile sections and components and associated test equipment; maintain logs and equipment histories.

Emergency Service Rating

Same as General Service Rating.

Navy Enlisted Classification Codes

For specific Navy enlisted classification codes included within this rating, see Manual of Navy Enlisted Classification, NavPers 15105 (Revised), codes GF-7800 through GF-7899.

Qualifications for Advancement in Rating

Qualifications for advancement in rating	Applicable rates GF
100 PRACTICAL FACTORS	
101 OPERATIONAL	
1. Demonstrate under simulated conditions the rescue of a person in contact with an energized electrical circuit, resuscitation of a person unconscious from electrical shock, and treatment for electrical burns	3
2. Handle, stow, and secure missile sections and components, excluding ordnance and propulsion equipment, on own ship or station; replace desiccant and recharge containers, if required for equipment	3
3. Unpack and prepare missile sections and components for assembly; visually inspect connections, fittings, and mating surfaces for proper condition; clean and prepare mating surfaces	3

Qualifications for advancement in rating	Applicable rates GF
101 OPERATIONAL--Continued	
4. Assemble and disassemble missile sections as member of team, on own ship or station; aline and secure sections; install and remove wings and control surfaces; connect or disconnect fittings, if required for missile	3
5. Prepare missile and associated test equipment for missile system test by making proper connections, setting missile and test equipment switches, installing required measuring devices, and setting missile and components in proper location	3
6. Operate specialized missile test equipment under direct supervision; take and verify dial readings; vary signals and switch positions as directed	3
7. Secure missile and associated missile test equipment after missile system test; set all switches, knobs, and valves for shutting down test; bleed pressurized lines; disconnect all electrical, hydraulic, or pneumatic lines; remove measuring devices mounted on missile for test	3
8. Demonstrate knowledge of electrical, ordnance (solid-propellent rocket motors, high-explosive warheads, fuzes, igniters), fueling, high-pressure air, hydraulic, jet engine, and mechanical safety precautions	3
9. Charge missile internal guidance and control pressurized systems; prepare missile for charging by removing access plates and making required hose connections; charge missile system following check list instructions; use hand tools, charging unit, or air supply system	2
102 MAINTENANCE AND/OR REPAIR	
1. Select and use hand tools and small portable power tools necessary for assembly and replacement of parts in air-launched missiles	3
2. Make electrical connections and splices including soldered joints	3
3. Operate the following test equipment:	
a. Voltmeter	3
b. Ammeter	3
c. Ohmmeter	3
d. Multimeter	3
e. Megger	3
f. Tube tester	3
g. Battery tester	3
4. Locate and identify major components and subassemblies by reference to block diagrams and mechanical drawings	3
5. Draw and interpret schematic diagrams of electrical circuits; read and interpret wiring diagrams found in technical maintenance publications; identify electronic and mechanical symbols	3
6. Lubricate missile and missile test equipment in accordance with handbook instructions, on own ship or station	3

Qualifications for advancement in rating	Applicable rates GF
102 MAINTENANCE AND/OR REPAIR—Continued	
7. Perform tests on batteries for missile or missile test equipment; replace weak or faulty batteries . .	3
8. Clean commutators and commutator heads; replace brushes on missile and missile test equipment rotating electrical machinery such as dynamotor, motor, generator; replace dynamotors, generators, and motors.	3
9. Identify capacitors, resistors, and wiring by standard color code systems	3
10. Perform tests for short circuits, grounds, and continuity on missile and missile test equipment electrical circuits. Visually inspect for loose, damaged, broken, or burned components	3
11. Replace fuses, wiring, switches, plugs, jacks, and relays on electrical equipment; make connections .	3
12. Replace identified or isolated vacuum tubes and circuit components, electronic packages, relays, potentiometers, multielement plugs and jacks; clean contacts, terminal pins, and plugs; make solder connections.	3
13. Perform tests for short circuits, grounds, and continuity on missile and missile test equipment electronic circuits; adjust potentiometers and controls; substitute components	2
14. Operate the following test equipment:	
a. Oscilloscope.	2
b. Signal generator	2
c. Frequency meter.	2
d. Vacuum tube voltmeter.	2
15. Draw and interpret schematic diagrams of electronic circuits; read and interpret wiring diagrams of electronic circuits found in technical maintenance publications	2
16. Effect changes to electronic circuits in accordance with wiring diagrams or field change instructions	2
17. Perform calibration and adjustments of missile-borne telemetering equipment on own ship or stations	2
18. Perform and supervise all tests for short circuits, grounds, and continuity on missile and missile test equipment electrical circuits; visually inspect for loose, damaged, broken, or burned components and repair or replace as required	2
19. Perform casualty analysis of malfunctioning hydraulic or pneumatic missile systems; locate leaks; visually inspect for damage; adjust fittings and movements and free bound parts; effect replacement or substitution of parts; retest system for proper operation.	2
20. Determine missile axes and angles of incidence; set trim tabs; use clinometers, gages, protractors, or jigs, as required.	2
21. Perform functional tests on missile system; direct and coordinate operation of specialized test equipment; observe motion of control surfaces and/or dial readings; adjust, aline, and calibrate	

Qualifications for advancement in rating	Applicable rates GF
102 MAINTENANCE AND/OR REPAIR—Continued	
components within allowable tolerances; reject malfunctioning missiles or sections	2
22. Trace signals through electronic circuits, using an oscilloscope; determine and compare waveforms with established or standard forms.	2
23. Calibrate tachometer generators on own ship or station; direct and coordinate operation of test and calibration equipment.	2
24. Perform missile component tests; isolate and locate malfunctioning components; check test equipment for proper operation; coordinate and direct test equipment operators; replace or repair defective equipment excluding tender/yard maintenance; determine signal inputs for measuring component responses	1
25. Operate the following test equipment:	
a. Spectrum analyzer.	1
b. Pulse generator	1
c. Sweep generator	1
d. Impedance bridge	1
e. Resistance bridge	1
f. RF wattmeter.	1
26. Perform casualty analysis of malfunctioning electromechanical, electrohydraulic, or electropneumatic systems including servo systems; disassemble units and make adjustments, replacements, or repairs excluding tender/yard maintenance	1
27. Perform casualty analysis of malfunctioning electronic power supplies and regulators; isolate, locate, and replace electronic components, assemblies, subassemblies, and detailed parts	1
28. Perform casualty analysis of free and rate gyroscopes, gyro control and autopilot systems; trace malfunctions from test data information by testing associated mechanical and electrical components for proper operation; check for proper gyro output signal; observe caging and erecting mechanism for proper operation; aline synchros to electrical zero; aline a servo indicating or setting system; replace malfunctioning gyroscopes	1
29. Perform delicate balancing and adjustment and alinement tests on electronic and electrical circuits and test equipment components; reduce data and make corrections; compare values, set predetermined values and check responses	C
30. Analyze graphic recorder records	C
31. Perform casualty analysis of malfunctioning missile and missile test equipment systems and components; effect allowable repairs	C
32. Perform casualty analysis of malfunctioning missile-borne telemetering components on own ship or station; analyze graphic recorder signals; calibrate and test frequency and proper operation of channels; isolate inoperative channels by making station	

Qualifications for advancement in rating	Applicable rates GF
102 MAINTENANCE AND/OR REPAIR—Continued	
checks; replace components which cannot be tuned within allowable limits	C
103 ADMINISTRATIVE AND/OR CLERICAL	
1. Maintain required shop and equipment work logs; log work accomplished; record test data	3
2. Maintain electronic equipment histories; prepare job orders, work requisitions, and failure reports	2
3. Supervise unpacking, handling, and stowage of missiles and missile components, excluding ordnance equipment; direct movement of missile, missile sections, and components in transporting, placing on test stand, assembly rack, and stowage racks	2
4. Inspect work performed in preparation of missile and associated test equipment for missile system tests for optimum operation of equipment	2
5. Supervise and instruct personnel in charging pressurized systems, replacement of parts and components, performance of missile functional and systems tests, and circuit repairs	1
6. Inspect work performed in maintenance and repair of missile guidance, control, and telemetering systems; inspect for proper test and adjustment procedures to insure optimum operation of equipment	1
7. Determine quantities and obtain part and stock numbers from technical and supply publications for tools, spare equipment, and replacement parts; requisition, store, and account for materials and spare parts	1
8. Supervise and instruct personnel in all guided missile safety precautions	C
9. Supervise and instruct personnel in performance of missile system and component tests	C
10. Inspect work performed in maintenance and repair of electronic power supplies and regulators and electrohydraulic or electropneumatic systems included in missile internal guidance and control	C
11. Organize work assignments and supervise personnel to accomplish maintenance projects as directed	C
12. Organize and maintain technical library of missile publications and other data required by technical bureau concerned	C
13. Evaluate completed equipment check lists, shop and equipment work logs, equipment histories and equipment failure reports; review stub requisitions for spare parts, tools, and materials	C
14. Prepare reports covering condition and status of missiles and associated equipment	C
15. Conduct and evaluate inventories of missiles, associated material, tools, and test equipment	C
200 EXAMINATION SUBJECTS	
201 OPERATIONAL	
1. Safety precautions to be observed in working with or near explosive ordnance, electrical, fueling,	

Qualifications for advancement in rating	Applicable rates GF
201 OPERATIONAL--Continued	
high-pressure air, hydraulic, and mechanical equipment	3
2. Effects of electrical shock, method of resuscitation of a person unconscious from electrical shock; treatment for electrical burns	3
3. Types and purposes of common tools used in assembly and disassembly of missile sections and missile containers	3
4. Purpose and application of desiccants in missile stowage; interpretation of desiccant colors	3
5. Types of missile guidance, stabilization, and propulsion systems	3
202 MAINTENANCE AND/OR REPAIR	
1. Types, structures, maintenance procedures, and electrical characteristics of batteries used in missiles and missile test equipment	3
2. Methods of cleaning commutators and commutator heads and precautions to be observed	3
3. Identification of standard electronic parts symbols used in schematic drawings	3
4. Types of information shown and meanings of electrical and mechanical symbols used in schematic diagrams of missile equipment	3
5. Identification of parts using electromechanical assembly drawings	3
6. Electrical and physical characteristics of electric motors, generators, and dynamotors	3
7. Soldering materials and soldering methods used in maintenance and repair	3
8. Methods and equipment used in electrical tests for continuity, grounds, and short circuits	3
9. Applications of laws of magnetism to d-c motors and generators	3
10. Meaning of:	
a. Conductors and insulators	3
b. Lines of force	3
c. Field intensity	3
d. Flux density	3
e. Permeability	3
f. Ampere-turns	3
g. Hysteresis and eddy currents	3
h. Self and mutual induction	3
i. Electromagnetic induction	3
j. Coulomb	3
k. Volt	3
l. Ampere	3
m. Ohm	3
n. Henry	3
o. Circular mil	3
p. Farad	3
q. Watt	3
r. Kilowatt	3
s. Power factor	3
t. Kilovolt-amperes	3

Qualifications for advancement in rating	Applicable rates GF
202 MAINTENANCE AND/OR REPAIR--Continued	
u. Reactance	3
v. Capacitance	3
w. Inductance	3
x. Impedance	3
y. Torque	3
z. Frequency	3
aa. Cycle	3
bb. Phase	3
11. Function of following measuring devices in electrical circuits:	
a. Ohmmeters	3
b. Meggers	3
c. Ammeters (a-c and d-c)	3
d. Voltmeters (a-c and d-c)	3
e. Frequency meters	3
f. Wheatstone bridge	3
g. Thermocouple instruments	3
12. Function of the following in hydraulic and pneumatic systems:	
a. Pneumatic gages	3
b. Check valves	3
c. Reducing valves	3
d. Safety valves	3
e. Restrictors	3
f. Actuators	3
g. Gaskets	3
h. O-rings	3
i. Manifolds	3
j. Pressure regulators	3
k. Flow regulators	3
l. Micronic filters	3
m. Servo valves	3
13. Function of the following in electrical circuits:	
a. Resistors	3
b. Rheostats and potentiometers	3
c. Solenoids	3
d. Inductors	3
e. Capacitors	3
f. Fuses	3
g. Switches	3
h. Transformers	3
i. Relays	3
j. Copper oxide rectifiers	3
k. Selenium rectifiers	3
14. RMA color coding systems for capacitors and resistors	3
15. Relationship of length and cross-sectional area to resistance of a conductor	3
16. Relationship of temperature, pressure, and volume in gases	3
17. Relationship of resistance, temperature, and current in an electrical conductor	3
18. Calculate current, voltage, and resistance in d-c series and parallel circuits containing not more than four elements	3

Qualifications for advancement in rating	Applicable rates GF
202 MAINTENANCE AND/OR REPAIR—Continued	
19. Relationship of resistance, inductance, and capacitance in a-c circuits	3
20. Relationship of current, voltage, and impedance in a-c circuits	3
21. Theory of permanent-magnet moving-coil meters with knowledge of shunts and of multiplier resistors	3
22. Current, voltage, and impedance relationships in series and parallel resonant circuits	2
23. Calculate current, voltage, phase angle, impedance, and resonance in a-c series and parallel circuits containing not more than a combination of four elements	2
24. Effects of meter sensitivity in circuit voltage measurement	2
25. Types and purpose of gas-filled tubes and cathode ray tubes; and function of each of their elements.	2
26. Purpose and function of diode, dry disk, and crystal rectifiers; purpose and function of triode, tetrode, and pentode vacuum tubes and function of each of their elements	2
27. Function of oscilloscope, tube tester, electronic voltmeter, signal generator, frequency meter, spectrum analyzer, pulse generator, impedance bridge, resistance bridge, RF wattmeter, and FM signal generator	2
28. Function and operating characteristics of missile pneumatic systems and components	2
29. Function and operating characteristics of missile hydraulic systems and components	2
30. Function and operating principles of check valves and solenoid-operated valves in missile hydraulic and pneumatic systems	2
31. Function and operating principles of pressure regulators in missile hydraulic and pneumatic systems	2
32. Methods of adjusting flow and pressure regulators used in missile hydraulic and pneumatic systems	2
33. Function and operating principles of gear and piston type pumps used in missile hydraulic systems	2
34. Function and operating principles of solenoid-operated hydraulic actuators used in missile aerodynamic control systems	2
35. Proper method of locating casualties by localizing to main unit, subassembly, circuit, and component	1
36. Proper method of making RF power measurements	1
37. Methods of coupling: Transformer, impedance, capacitance, resistive, direct, and tuned; purpose for and methods of achieving impedance matching in circuits	1
38. Function of half-wave, full-wave, and bridge-type rectifiers and voltage doublers; simple voltage regulators and gaseous-type regulator tubes; function of capacitor and choke input filters	1
39. Applications of low-pass, high-pass, and band-pass filters	1
40. Operating principles of diode, dry disk, and crystal rectifiers	1

Qualifications for advancement in rating	Applicable rates GF
202 MAINTENANCE AND/OR REPAIR—Continued	
41. Operating principles of half-wave, full-wave, and bridge-type rectifiers and voltage doublers; simple voltage regulators and gaseous-type regulator tubes	1
42. Functions and applications of servomechanisms and synchros as applied to missiles and missile test equipment	1
43. Methods of making gain, phase, balancing, and zeroing adjustments to servo loops found in missile internal guidance and stabilization systems	1
44. Function and physical and electrical characteristics of free and rate gyroscopes including caging and erecting devices	1
45. Function of the following:	
a. Audio amplifiers	1
b. RF amplifiers	1
c. Video amplifiers	1
d. Cathode followers	1
e. Oscillators: Hartley, crystal-controlled, Colpitts, TPTG, electron-coupled	1
f. Diode and crystal detectors	1
g. Modulators	1
h. AGC circuits	1
i. AFC circuits	1
j. Discriminators	1
k. Phase shifters	1
l. Differentiators	1
m. Integrators	1
n. Trigger circuits and multivibrators	1
o. Coincidence circuits	1
p. Limiters	1
q. Clippers	1
r. Peakers	1
s. Clampers	1
t. Counting circuits	1
u. Sawtooth generators	1
v. Wire and coaxial transmission lines and waveguides	1
w. T/R and AT/R tubes	1
x. Klystrons	1
y. Magnetrons	1
z. Crystal mixers	1
aa. Photoelectric cells	1
46. Electrical characteristics of Hertz, Marconi, and dipole antennas. Principles of operation of dish reflectors and of parasitic reflectors and directors	C
47. Operating principles of modulation: Amplitude, frequency, phase, and pulse	C
48. Operating principles of those circuits or elements listed in item 202-45	C
203 ADMINISTRATIVE AND/OR CLERICAL	
1. System of assigning "AN" letter-number combinations as designation for electronic equipment	3
2. Application of allowance lists in determining spare parts, tools, and supplies kept on board	1

Qualifications for advancement in rating	Applicable rates GF
203 ADMINISTRATIVE AND/OR CLERICAL--Continued	
3. Procedures for obtaining replacement parts and supplies; maintenance of inventory.	1
300 PATH OF ADVANCEMENT TO WARRANT OFFICER AND LIMITED DUTY OFFICER	
Aviation Guided Missilemen advance to Warrant Aviation Ordnance Technician and/or to Limited Duty Officer, Aviation Ordnance. As an alternate, Aviation Guided Missilemen advance to Warrant Aviation Electronics Technician and/or to Limited Duty Officer, Aviation Electronics.	

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